A Guide to the AMSAT CubeSatSim

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Figure 1 — The AMSAT CubeSatSim with tape measure dipole antenna.

Abstract — The AMSAT CubeSatSim is a small, low-cost, spacecraft simulator that serves as a tool for academic education, public demonstrations and theory and design disciplines. It can be used in a classroom, lab or training setting to introduce the basics of satellite operations, or it can be used to teach STEM (Science, Technology, Engineering, Math) exercises. This article is a guide to using, building, and extending the CubeSatSim. We hope that this information will help the readers understand what they can do with a CubeSatSim, how to build or borrow one, and how to participate in the CubeSatSim project.

Overview

The AMSAT CubeSatSim model is shown in Figure 1. The AMSAT CubeSatSim, our CubeSat Simulator, is a Raspberry Pi Zero-based, 3D printed, functional model of a 1U form factor CubeSat. It is designed to act, as reasonably as possible, as one flying in Low Earth Orbit (LEO) to demystify how satellites work. The construction plans and software are fully open-sourced, and information about building one is available at

Figure 2 — CubeSatSim Simulator Loaner.

cubesatsim.org. Like real LEO satellites, this simulator is self-powered through onboard rechargeable batteries and solar panels. It transmits telemetry wireless on UHF in a variety of formats. For details on the design and construction of the simulator, see our article in the March/April 2020 issue of *The AMSAT Journal* (cubesatsim.org/content/

CubeSatSimPaper5.pdf). A lot of good information is available at the CubeSatSim Project page cubesatsim.org.

This article is designed to provide a user's guide to the CubeSatSim to help the readers become familiar with the capabilities and options associated with it, and how they can

build or borrow one.

Build or Borrow?

Since the start of the program, AMSAT has supported the development of the CubeSatSim and also made loaner units available for classrooms and public demonstrations. If you are interested in using a CubeSatSim in your classroom, presentation, or demonstration, you might want to consider borrowing one of the loaner units to learn about it and get some experience operating it. Just contact AMSAT's VP of Educational Relations, Alan at ku2y@amsat.org for details.

The CubeSatSim loaner, as shown in Figure 2, comes in a rugged container containing:

- A fully assembled CubeSatSim
- A turntable to simulate spinning in space
- A lamp to simulate illumination by the sun
- An RTL-SDR dongle to make a simple ground station to receive radio signals and decode telemetry
- Charger and spare batteries

For now, your PC laptop is used in your ground station. In the future, a Raspberry Pi Ground Station will be included with the loaner, allowing for right out-of-the-box operation.

An online User Guide provides basic setup and usage instructions (github.com/alanbjohnston/CubeSatSim/wiki/User-Guide).

Some CubeSatSim builders have borrowed a simulator during their build to help them better understand the construction and testing. Other CubeSatSim borrowers have gone on to build their own after they return it.

Will There Be Kits?

This is a common question we get asked a lot about the CubeSatSim. The answer is yes, but we aren't sure exactly when. Before we realized what kind of year 2020 would be, we had grand plans to make CubeSatSim kits available at Hamvention 2020 and the AMSAT Space Symposium get-togethers. Besides the global pandemic, it has also taken longer than we expected to complete and test the new design of the CubeSatSim.

Getting parts from many sources has also been very challenging this year. Some parts are only available at a reasonable price directly from China, which makes for long and uncertain lead times. In the online Bill of Materials list cubesatsim.org/bom, we try to provide multiple alternative sources for parts.

Finally, order fulfillment is difficult these days with the AMSAT office shutdown and the lack of in-person meetings at universities and clubs. While an individual can do this work, it is a big job best done by an organization or group.

As such, we still plan to make kits available. These first kits will likely be the CubeSatSim Lite. Its printed circuit board will come with all surface mount devices (SMD) mounted so that it can be plugged into any Raspberry Pi and immediately used. Optional components can be soldered in by users to provide additional features.

We also plan to make printed circuit board sets available, possibly with the surface mount components pre-installed.

For the latest info on kits, check out the CubeSatSim Project Page (cubesatsim.org) and also the AMSAT Education Outreach Page (amsat.org/outreach).

Versions of the CubeSatSim

The original CubeSat Simulator was conceived, designed, and built by Mark Spencer, WA8SME, over ten years ago. It was known at the time as the ARRL ETP CubeSat Simulator, which is the foundation and inspiration for this simulator. *The AMSAT Journal* published his design, resulting in two major articles that are available online.

This version of the CubeSat Simulator, which we call the AMSAT CubeSatSim,
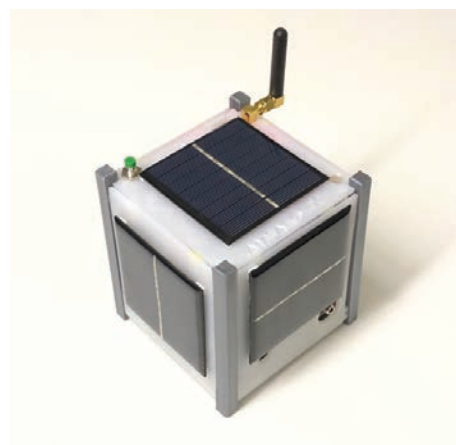

Figure 3 — Original AMSAT CubeSat Simulator.

was first prototyped two years ago. The development has been funded by AMSAT, the Radio Amateur Satellite Corporation, a not-for-profit education and scientific organization dedicated to "keeping amateur radio in space." The CubeSatSim is an important educational outreach activity designed to immerse radio, space topics, and STEM activities into classrooms and events.

The AMSAT CubeSatSim design is based on Mark's concept but has more of a software focus than a hardware focus. This has allowed us to evolve our design and easily add new functionality.

So far, two versions of our CubeSatSim hardware have been developed. The original design "launched" at Hamvention 2019 is the version that has been detailed in these *AMSAT Journal* articles, and is currently in the loaner units. This version is shown in Figure 3.

A newer version of the hardware has been under development in 2020, as shown in Figure 4. It reduces the cost and complexity of the build and provides more functionality and features than the original. For example, it supports multiple telemetry encoding modes.

We maintain a CubeSatSim Wiki on GitHub that has the designs and instructions for the latest version at (cubesatsim.org/wiki/). The "Lite" version of the CubeSatSim is discussed in the next section.

CubeSatSim vs CubeSatSim Lite

Early in the development of the AMSAT CubeSatSim a few years ago, we had the idea to have a "Full" version and a "Lite" version. The full version had working solar panels, rechargeable batteries, sensors for voltages, currents and temperatures, while the Lite version comprised only minimal workings that transmitted pre-recorded telemetry. The initial Lite version transmitted telemetry over an unused channel of the commercial FM broadcast band. The telemetry was a pre-recorded AFSK audio file that was transmitted over and over. Only a Raspberry Pi and a short length of wire for an antenna were needed to build this minimal Lite version.

The latest version of the CubeSatSim Lite is more involved. It is essentially a "mocking bird" of the full CubeSatSim, being without rechargeable batteries, solar panels, and current and voltage sensors. Simulated telemetry is generated in software which then allows all the telemetry modes of the CubeSatSim to be used: audio frequency-
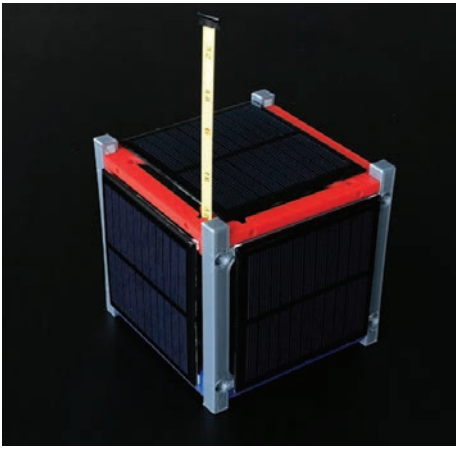
Figure 4 — Latest Version of the AMSAT CubeSatSim with a tape measure monopole antenna.

Figure 5 — CubeSatSim Lite in a Frame with a USB power pack.
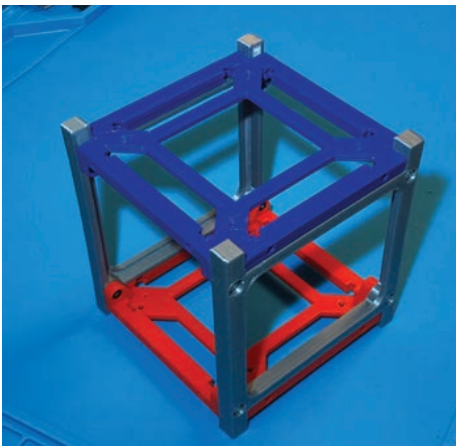

Figure 6 — CubeSatSim 3D Printed Frame.

shift keying (AFSK), frequency-shift keying (FSK), and binary phase-shift keying (BPSK). Slow Scan Television (SSTV) image transmission also is supported.

A minimal CubeSatSim Lite "flight" unit consists of the CubeSatSim board, a Raspberry Pi, and an antenna. The CubeSatSim can be mounted in a 3D printed frame and powered by a USB power pack, as shown in Figure 5. Users can also interact with the CubeSatSim via a USB serial port connection to a laptop or other computer. In the future, look for a series of educational activity plans to become available using the CubeSatSim Lite.

What To Do with your CubeSatSim

There are many things you can do with a CubeSatSim, covering a wide range of audiences and individual and group activities. Here are some ideas.

Physical Activities

Firstly, the AMSAT CubeSatSim is a physical model of a 1U CubeSat, which can be great for visualization of an actual educational spacecraft. You can pass it around so others can feel and touch it. You can use it to discuss the requirements of an actual spacecraft, the differences between the Simulator and a real CubeSat space flight model, and also the similarities. Many schools, Public Libraries and Makerspaces have 3D printers so you can print and assemble your own frame, as shown in Figure 6, at a very low cost. The open-sourced 3D print files for downloading a frame can be found at www.thingiverse.com/thing:4333605.
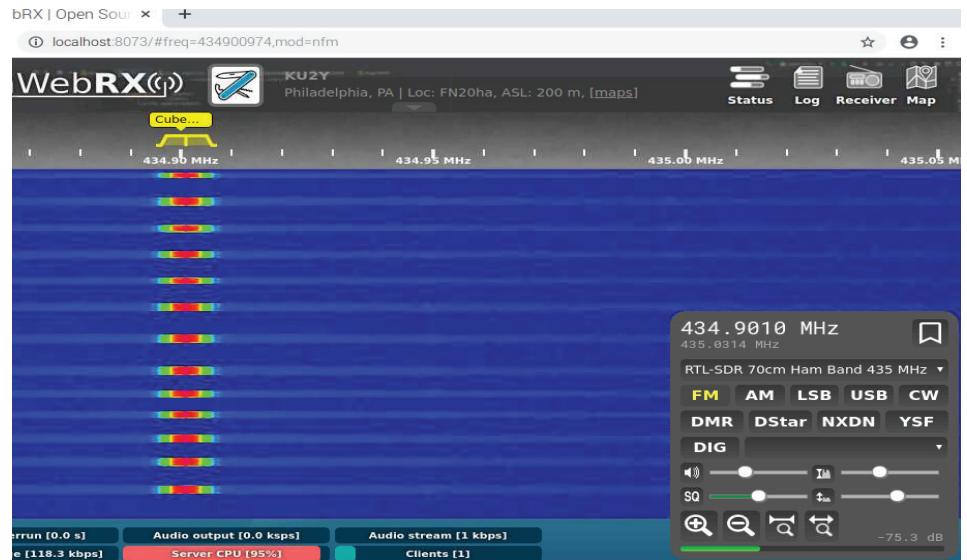

Figure 7 — CubeSatSim AFSK (Audio Frequency Shift Keying) Modulation.
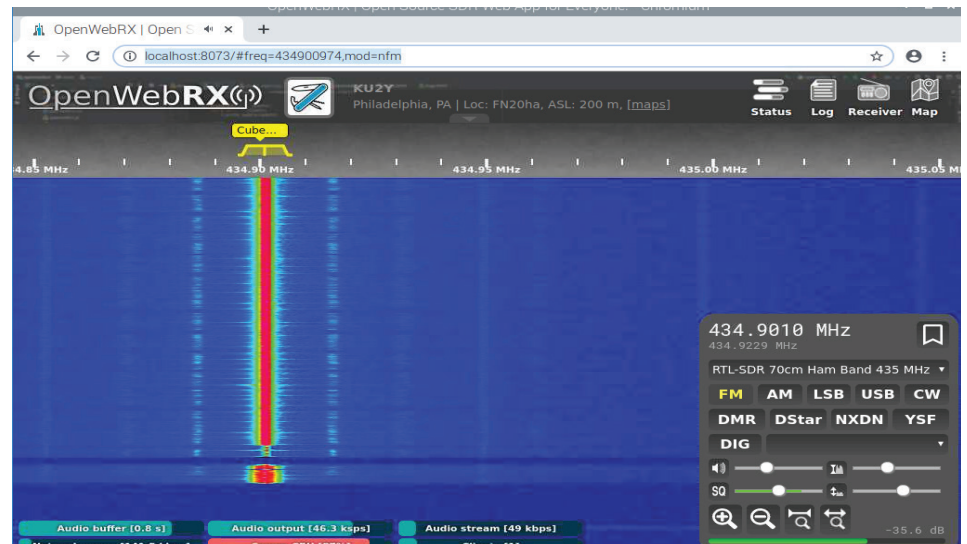

Figure 8 — CubeSatSim FSK (Frequency Shift Keying) DUV (Data Under Voice) Modulation.

Listening Activities

The CubeSatSim transmits radio telemetry in various modes. Each of these modes has different technical characteristics as well as different sounds when listened to on a physical radio or a software-defined radio (SDR). A fun first activity can be to listen to the different telemetry modes and, if using a SDR, see how they look in a waterfall visualization. For example, see the four modulation examples in Figures 7, 8, 9, and 10.

After listening to and naming the modes, your group could try to identify a specific mode by the sound and the look of the waterfall.

If students have their own RTL-SDR dongle and software on their computer, they can tune the radio on their own. If a web SDR is available, multiple students can connect to it using just a web browser on their computer or phone and tuning the radio. See an example of a Raspberry Pi-based web SDR for the ARISS Radio Pi at github.com/alanbjohnston/CubeSatSim/wiki/Radio-Pi.

Radio Activities

Having a radio transmitter and receiver allows for a number of radio principles to be demonstrated. For example, the effect of radio "gain" can be observed by adjusting the receiving radio. The variation of signal strength with distance can be observed by changing the distance between the CubeSatSim and the receiver. Even some advanced radio topics such as polarization can be shown, by varying the orientation of the CubeSatSim transmitting antenna and the Ground Station receiving antenna.

Telemetry Decoding and Analysis Activities

The CubeSatSim transmits multiple channels of real life-like CubeSat housekeeping telemetry. By going over what information is transmitted and why, you can learn a lot about how a CubeSat is designed, and how it functions in space after launch.

With the Ground Station running FoxTelem software, as shown in Figure 11, the telemetry information can be decoded and displayed in real-time or exported to a spreadsheet for further analysis. After looking at the CubeSatSim telemetry, you can download the actual telemetry from AMSAT CubeSats on orbit and look at real data from space.

The CubeSatSim Lite will randomly generate simulated telemetry. By analyzing it, you can figure out if the spacecraft is in illumination or eclipse, has a healthy battery charge or low charge, is spinning, and about which axis or axes.
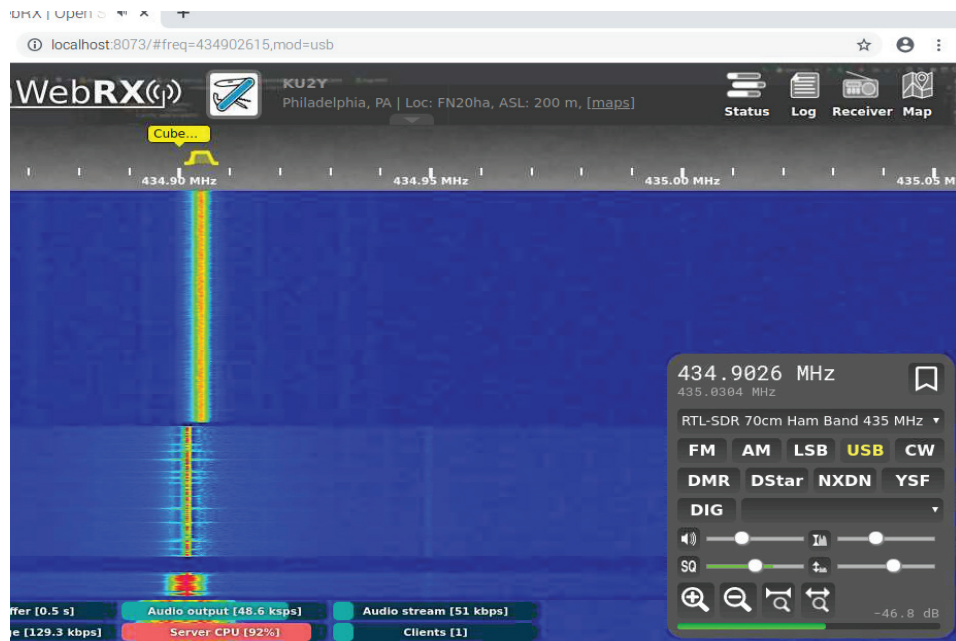
By placing a CubeSatSim on a turntable in front of a lamp, you can generate real telemetry and analyze it in real time. The LED lamp shining on the solar panels will generate voltages that can be analyzed in the telemetry. LED illumination only generates a very small current, but if you place the CubeSatSim in sunshine, you will see larger currents flow. You will also see that the solar panels are charging the battery.

Any standard SSTV decoding software can be used to decode the SSTV transmissions from the CubeSatSim. For example, Figure 12 shows MMSTV on Windows decoding an image.
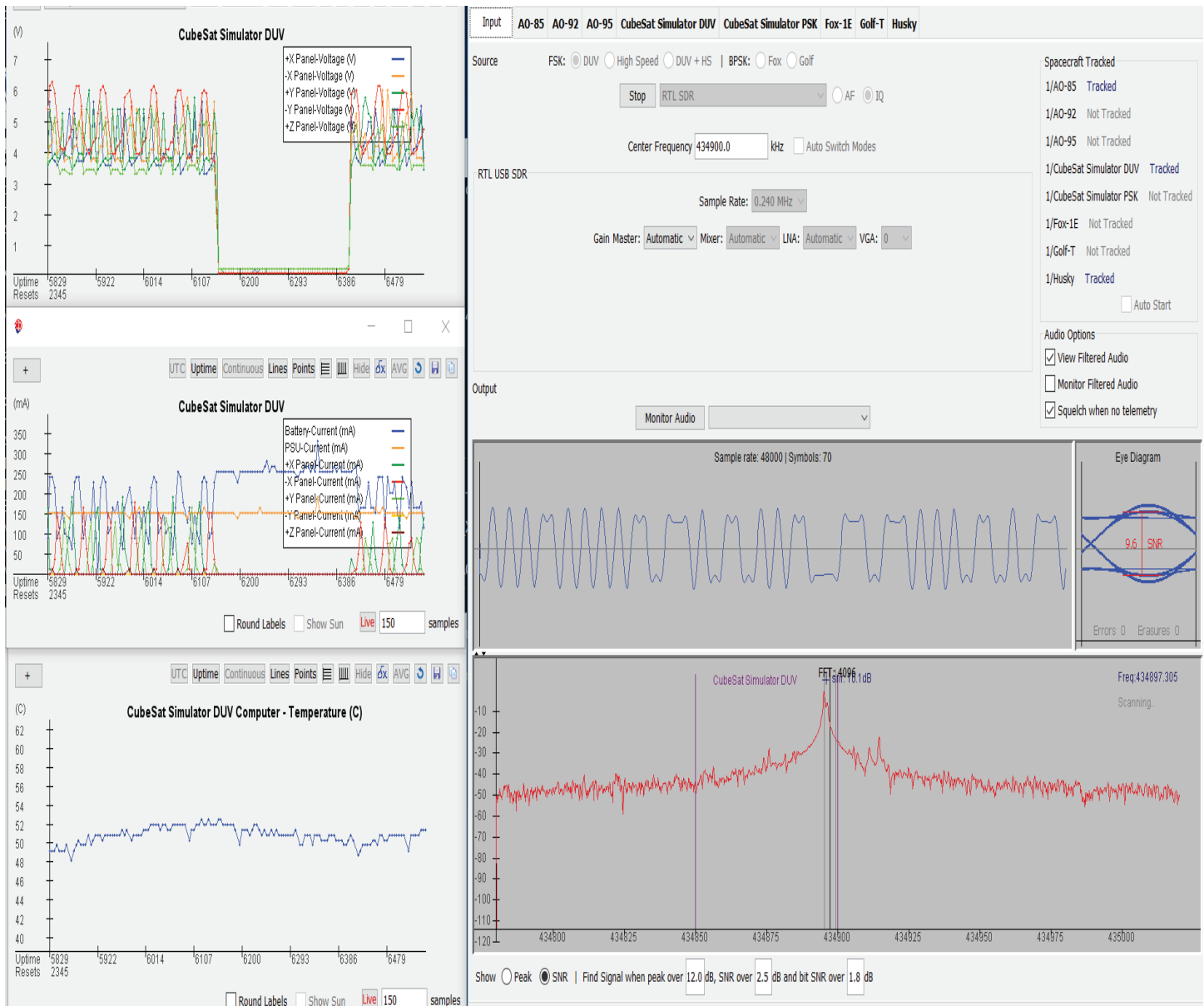

Figure 9 — CubeSatSim BPSK (Binary Phase Shift Keying) Modulation.
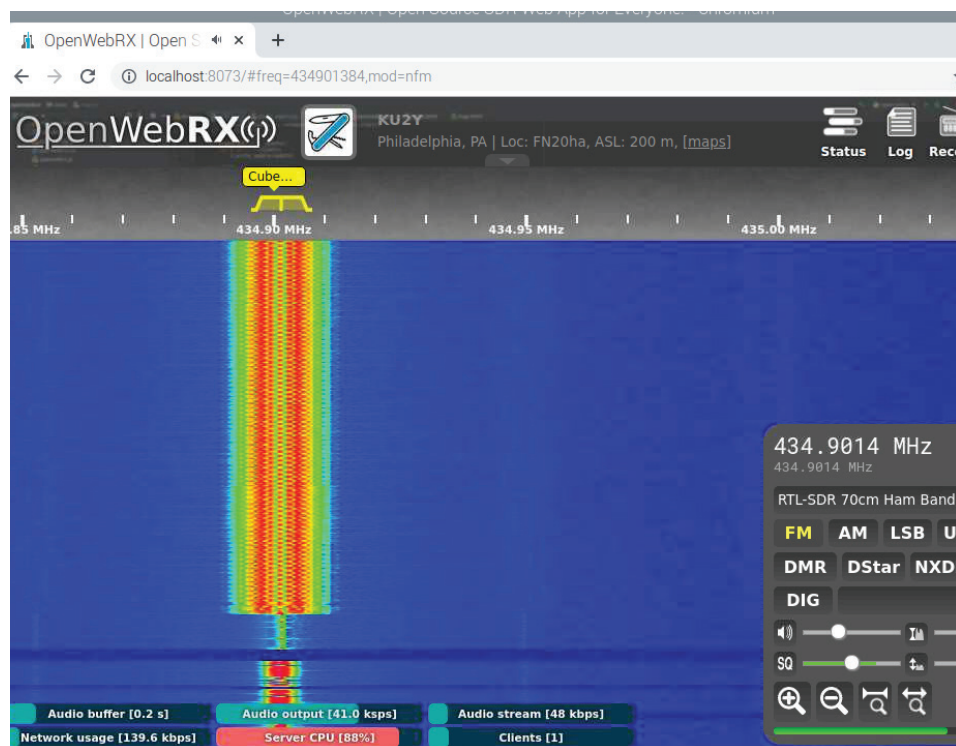
Figure 10 — CubeSatSim SSTV (Slow Scan TV) Signal.

Figure 11 — FoxTelem Telemetry Analysis of the CubeSatSim.

A given CubeSat flight unit features a self-contained powered system, and the CubeSatSim allows you to learn about it. With a simple Digital Multimeter (DMM), you can measure voltages and currents using the meter and compare them to the sensor outputs. You can characterize the current-voltage (I-V) curve of the solar panels and look for variations among the different panels. You can simulate failures and problems in the CubeSat, and then troubleshoot them using telemetry.

Sensor Activities

The STEM Payload board provides a number of sensors for the CubeSatSim. A STEM Payload Board can even be plugged into a CubeSatSim Lite if it has the stacking GPIO header. See the section on the STEM Payload Sensors in this article for more information.

Design Activities

Students with an understanding of electronics can analyze the design of the CubeSatSim and compare it with the design of a real CubeSat flight model. The different functional areas can be studied separately: Electrical Power Subsystem (EPS), Command and Data Handling (CD&H), Flight Software (FSW), mechanical spaceframe (MECH), etc.

Development Activities

The CubeSatSim is designed to be extensible. Students with a software or electrical background can propose and implement changes and upgrades to the design. Some interesting ideas include:

- Modify to make a 2U CubeSatSim
- Upgrade with more powerful solar panels
- Install a small motor to act as a gyro to serve as a momentum wheel
- Add a receiver and implement a command channel to control it, for example, to turn telemetry on and off
- Implement new features in software, either C language or Python code
- Add additional sensors to the STEM Payload Board with Arduino programming
- Redesign for a balloon launch
- Write a user interface to control the CubeSatSim Lite over the serial port
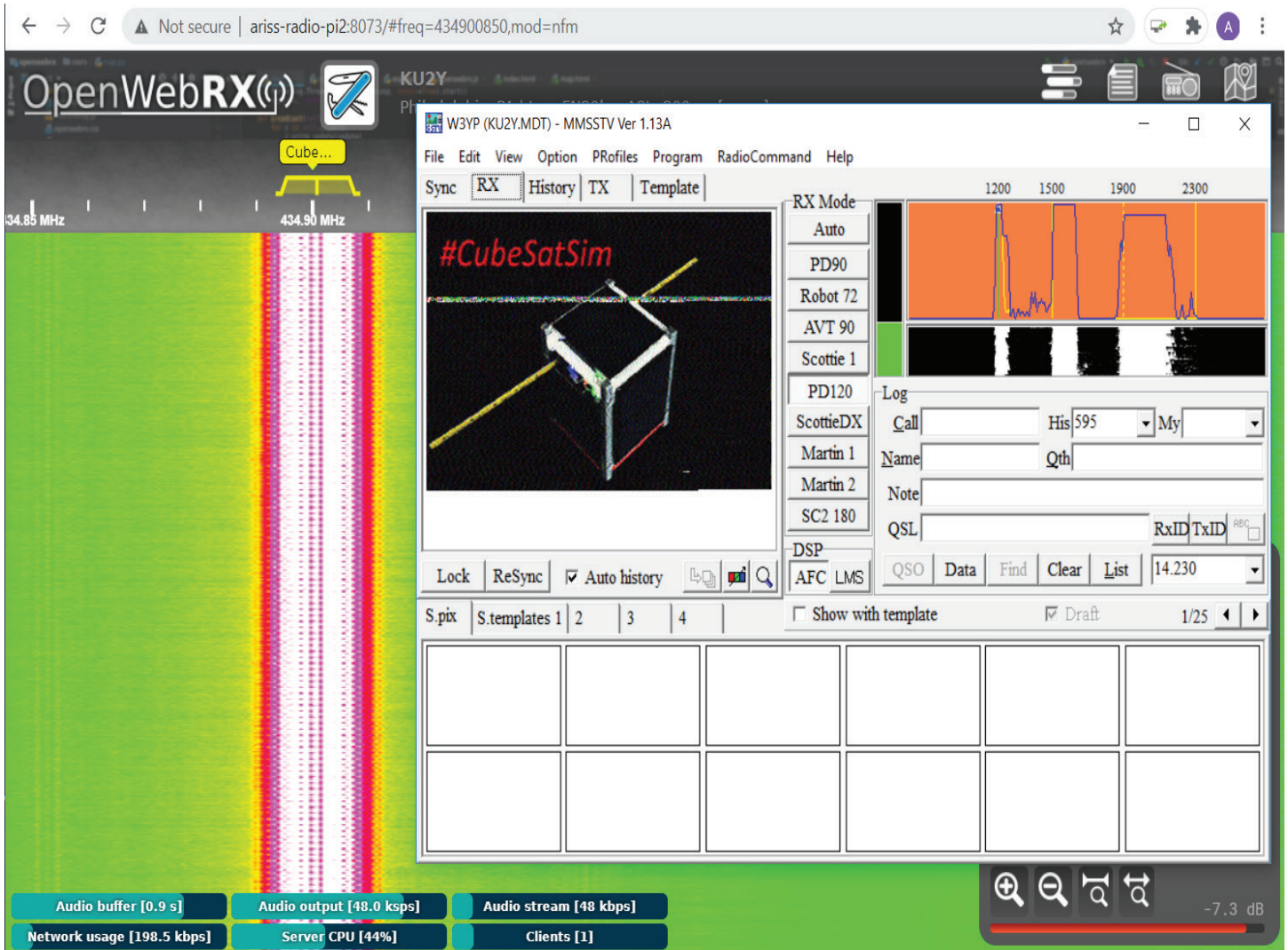- Add more advanced simulated telemetry

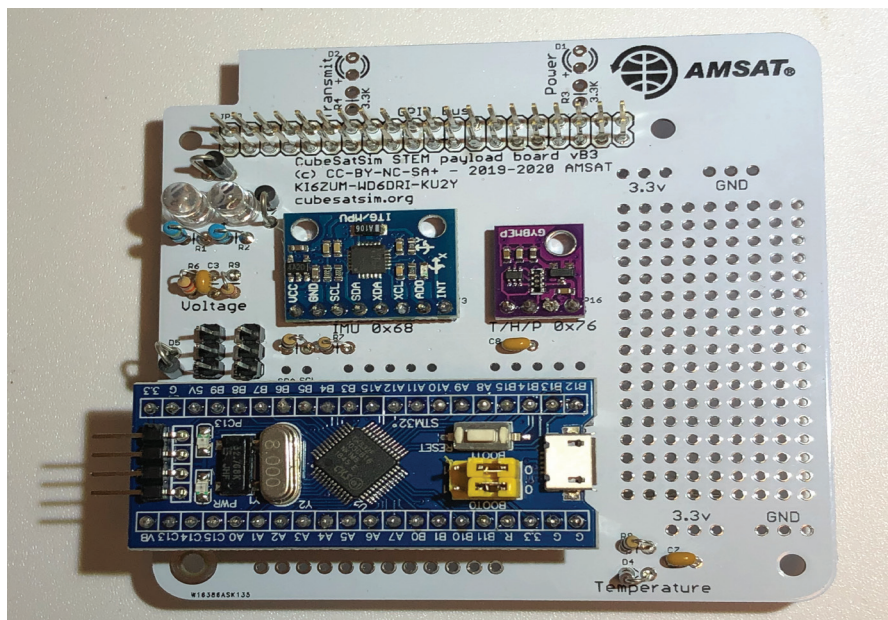Figure 12 — SSTV Decoding using MMSSTV Electronics Activities.

Figure 13 — CubeSatSim STEM Payload Board with STM32 Microcontroller.

STEM Payload Sensors

A full description of the STEM Payload and the available sensors is a topic for a future article, but we can summarize it here. Just like a real spacecraft in orbit, the CubeSatSim separates the basic housekeeping operation of the CubeSat, which runs on the Raspberry Pi Zero WH, and the science telemetry from the sensor payloads, which run on an Arduino compatible microcontroller. The three controllers currently supported are the Sparkfun Pro Micro and the STM32 "blue pill" and "black pill." Communication between the Pi and the Arduino occurs over a serial interface.

By extending the payload software, you can add additional sensors for experiments and other potential discoveries.

The two built-in STEM Payload Sensors are a BME280 sensor and an MPU6050 sensor. The BME280 provides atmospheric pressure, relative humidity, and temperature.

The MPU6050 provides a 3-axis gyroscope and a 3-axis accelerometer. Also, a forward-biased 1N4148 diode is connected to an analog input. The voltage drop across the diode varies approximately linearly with temperature, allowing a simple temperature sensor to be calibrated and displayed. The board also has a prototyping area for adding additional sensors and functionality. Figure 14 shows the MPU6050 sensor rotation in degrees per second (dps) in the X, Y, and Z axes analyzed with FoxTelem.

Ordering Parts to Build Your Simulator

If you have decided to build your own CubeSatSim from scratch, the first step is to order your parts. The complete BOM is at cubesatsim.org/bom.

We have tried to list multiple sources for each component where possible. Sometimes, a particular supplier is out of stock. If you have difficulty with the listed sources, let us know via email or social media so we can fix it. You have various choices in your design.

For example:

CubeSatSim versus CubeSatSim Lite: See the earlier section on the differences. The CubeSatSim Lite is cheaper to build but doesn't have full functionality.

PCBs: Do you want to get your own printed circuit boards (PCBs) fabricated or get them from AMSAT in the future? Making them yourself can be a lot of fun, and you can even customize them and add your name or organization to the silkscreen. However, a likely minimum quantity order (often 3 or 5) is a pain if you are building just one CubeSatSim. On the other hand, the extra boards make good giveaways or drink coasters ;-). Designs may already be uploaded to a fabricator, in which case you just need to select one or more and place the order with a click.

SMD Parts: Most of the CubeSatSim employs printed through-hole (PTH) mounted components to simplify hand soldering, and there are some surface mount

(SMD) parts. Hand-soldering them is possible if you have a steady hand, sharp eyesight and good soldering skills. Or, if you have access to a reflow oven, the process is straightforward. Otherwise, look for a PCB with the SMD parts already mounted.

Type of antenna: Do you want to make a tape measure antenna like a real CubeSat, or do you want the flexibility of an SMA-connected antenna? Note that the RF energy from a CubeSatSim should never be connected to an amplifier or high gain antenna without additional filtering. The existing bandpass filter (BPF) is suitable for extremely low power transmissions but is not suitable for higher power.

AAA or AA batteries: The CubeSatSim can be built with either AAA or AA batteries. With their extra capacity, AA batteries will run the Simulator longer, which can be good for all-day demonstrations. However, if you are looking to demonstrate the charging/discharging functionality, having a larger battery capacity means your experiments
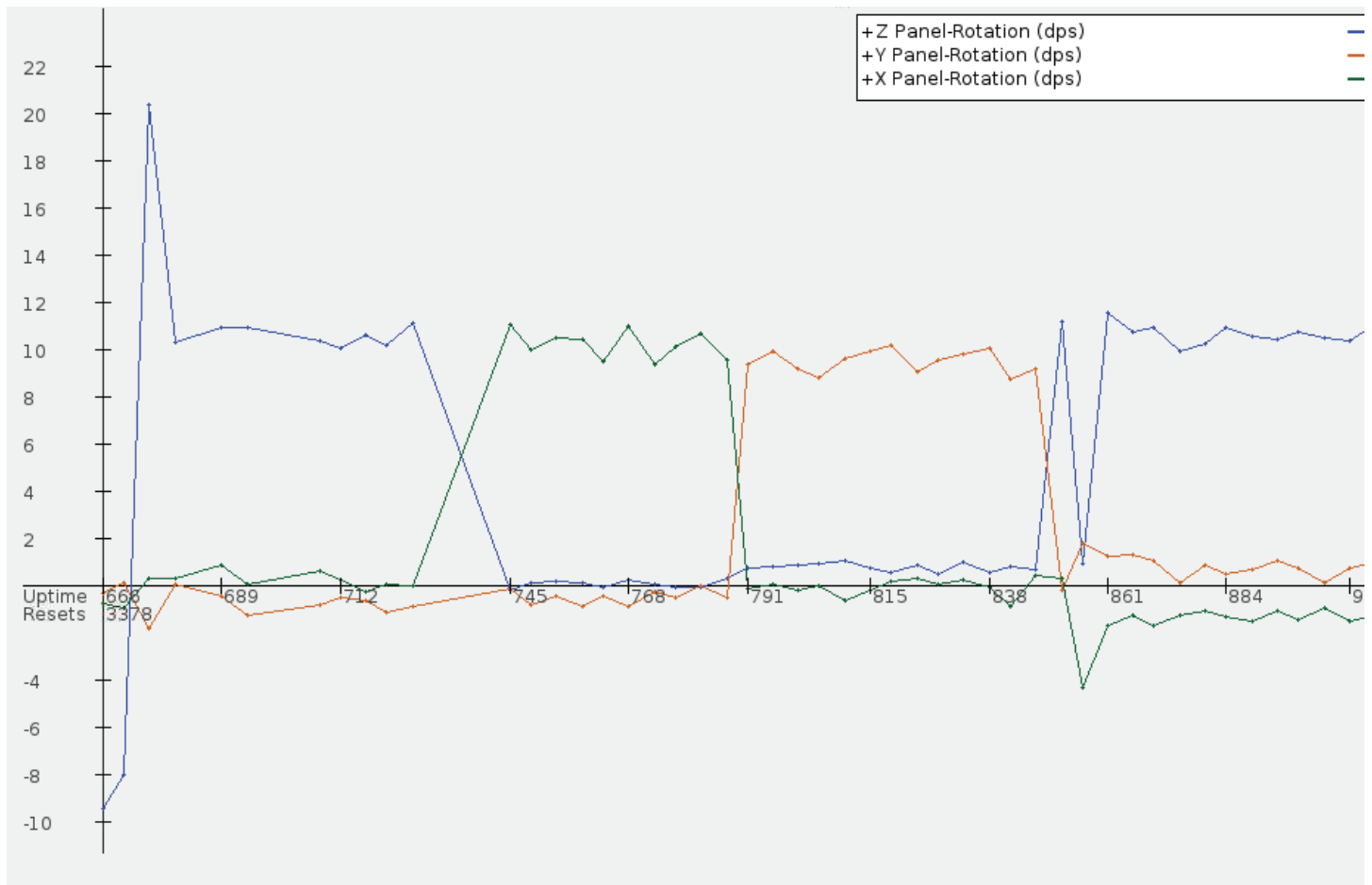

Figure 14 — X, Y, and Z Rotation of CubeSatSim analyzed using FoxTelem.

will take longer. The AAA batteries allow voltage changes to appear in just a few minutes compared to tens of minutes for the AA batteries.

3D Frame: Will you print your own or order a print by following the steps at github.com/alanbjohnston/CubeSatSim/wiki/CubeSat-Frame?

Testing, Testing, Testing

Testing your CubeSatSim build as you go along is essential to your success. You do not want to finish the assembly and then begin to test it -- how will you find and isolate issues? The Wiki instructions have many in-progress tests that you can perform. Some tests don't require software installation, but many do. For example, here is a list of some of the tests described:

• Pi test
• Green LED test (software running)
• Red LED test (charging voltage from a power pack or solar panels)
• Blue LED test (transmit test)
• Push-button test (testing power up, shutdown, and changing modes)
• Transmit test (receiving radio signals on a conventional radio or SDR)

• Solar Panel test
• Solar Panel Voltage Sensing test
• Battery Sensing test
• 5V Bus Sensing test
• Running test
• Solar Panel Current Sensing Test
• STEM Payload Communication Test
• RBF Switch Test

Also, "FlatSat" testing can be performed with the CubeSatSim before stacking and assembly in the frame, as shown in Figure 15.

Operation of the CubeSatSim

If your build is complete, and your test results are "nominal," you are ready to operate your CubeSatSim!

First, I would recommend charging up your batteries using the Raspberry Pi charger. This is done best with the CubeSatSim off (hold the push-button until the green LED blinks slowly) and with the RBF switch inserted. The battery pack should charge up to around 4.5 V. Having a USB tester can be very helpful for seeing what is going on while charging. Amazon offers some example ones that cost around $20 (amazon.com/s?k=usb+tester).

Launching your CubeSatSim on a turntable in front of an LED light or in sunshine is a great "first flight." Set up your Ground Station or have a radio or SDR monitoring 434.900 MHz Narrowband FM (NFM). Disconnect the Power Supply and remove the RBF switch, and the CubeSatSim will boot up and, after about 30 seconds, begin transmitting.

First, you will hear a CW signal which is the text letters "de" (meaning "from"), then the callsign that you entered during the software installation. After a short pause, the CubeSatSim will begin transmitting telemetry. You can change the telemetry mode by pressing and holding the pushbutton, then releasing it after a certain number of fast flashes of the green LED. For example:

• Press and release after one blink of the green LED: switches to AFSK telemetry mode. After about 5 seconds, the telemetry mode will switch to AFSK. You will need software such as AFSK1200 Decoder and an SDR to decode the telemetry packets.
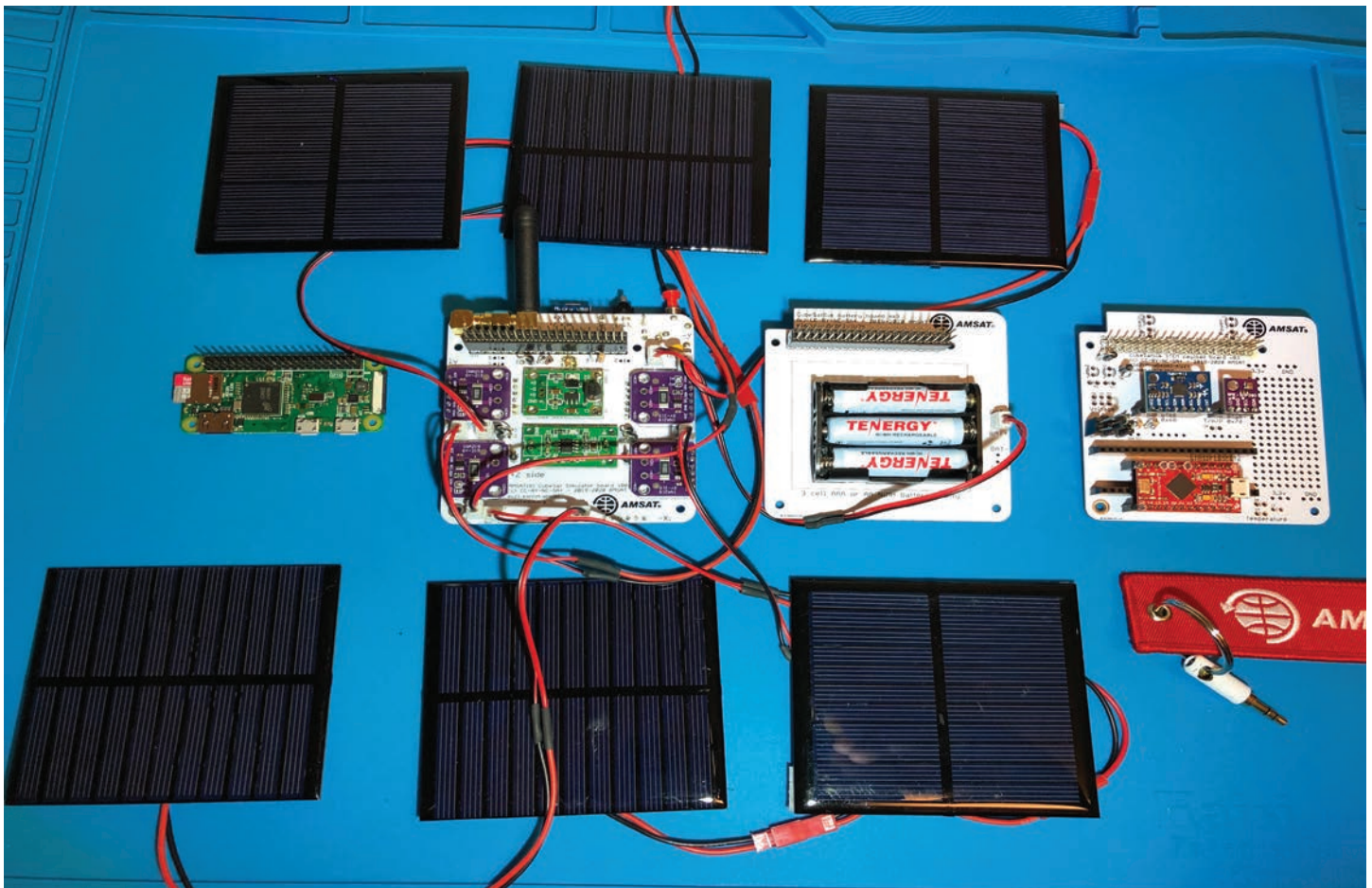

Figure 15 — FlatSat Testing of CubeSatSim.

- Press and release after two blinks of the green LED: switches to FSK mode. After about 5 seconds, the telemetry mode will switch to FSK. FoxTelem in FSK: DUV (Data Under Voice) mode will decode these telemetry packets.

- Press and release after three blinks of the green LED: switches to BPSK mode. After about 5 seconds, the telemetry mode will switch to BPSK. FoxTelem in BPSK: Husky/Golf mode will decode these telemetry packets.

- Press and release after four blinks of the green LED: switches to SSTV mode. The CubeSatSim will transmit SSTV images in PD120 format. You will need SSTV decoding software such as MMSSTV or QSSTV or others to decode.

Some fun things to look at in the telemetry include:

- Look for Solar Panel voltage peaks if it is rotating in front of a lamp. If the room is dark, you will get big spikes in the voltage. If you have a lot of ambient light, you will see small peaks. Verify the order based on the axes.

- In sunlight or in front of a halogen lamp, you will see current peaks. The angle of the solar panel to the incident light will determine the intensity of the peak. Try propping the CubeSatSim to change the angle, and see the peaks change.

- If you have the STEM Payload Board with the Gyro, look for the X, Y and Z rotation.

Watch for the battery voltage to fall over time. It will experience an initial drop when you disconnect the charger, perhaps from 4.5 V down to 4.2 V. After an hour or so, the battery voltage may drop to close to 3 V and you may observe the CubeSatSim shutting down into "safe mode." You must top them off again with the Raspberry Pi charger to be able to run on battery again.

You can look at the battery current during operation. It will be fairly constant except under sunlight illumination. If the solar panels output a measurable current, you will see the battery current drop by roughly the same amount. In very bright sunlight with good panels, you might even see the battery current go almost to zero. When charging on the Power Supply, the battery current will read negative. The initial current for a discharged battery will be high -- over 200 mA, but it will fall rapidly. A value of around 50 mA indicates that the battery is fully charged once again.

You can track the CPU temperature of the Raspberry Pi. It will gradually warm up a bit if you just started your CubeSatSim. In sunlight, you may see this temperature also go up. In eclipse, the temperature will fall.

Ground Station Options

There are various Ground Station options for the CubeSatSim.

The best option is to use the AMSAT FoxTelem software. It is built on open-source Java, so it runs on all platforms, including the Raspberry Pi! The new ARISS Radio Pi Raspberry Pi image has all the needed software pre-installed, as shown in Figure 16. For more information, see github.com/alanbjohnston/CubeSatSim/wiki/Radio-Pi.

You can also receive AFSK 1200 bps telemetry with a radio or SDR and software such as AFSK 1200 Decoder. Multimon-ng also decodes the telemetry.

Participating in the CubeSatSim Project

You can participate in the AMSAT CubeSatSim Project! Here are some of the ways:

- Document your CubeSatSim build and testing on social media
- Offer to demonstrate your CubeSat Simulator to local schools, your ham club, Makerspace or Hackerspace gatherings, or other STEM events

The official CubeSatSim Project Twitter account is **@CubeSatSim,** and we use the hashtag **#CubeSatSim** to highlight our activities.

Conclusion

This article offers a guide to the AMSAT CubeSatSim. We hope this information is useful to you and will help you decide what you will do with a CubeSatSim. We would love to hear questions you might have about items we didn't cover here, or issues or barriers to getting the CubeSatSim into classrooms and public demonstrations.
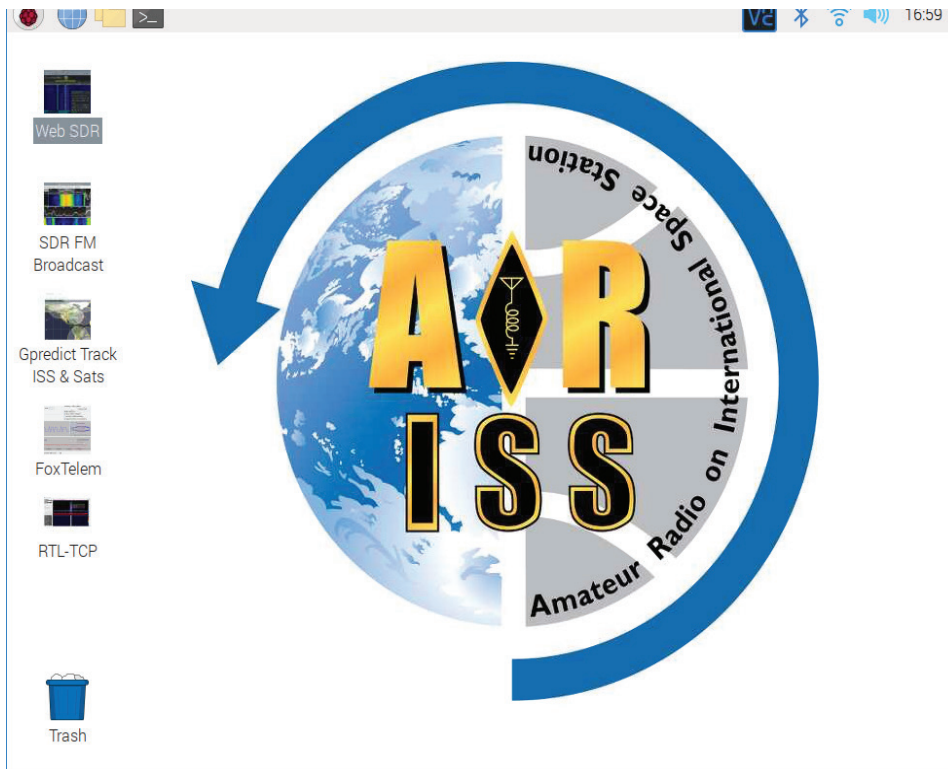

Figure 16 — ARISS Radio Pi Ground Station.

User Services Update

Robert Bankston, KE4AL
VP User Services

With my promotion to AMSAT President, this will be my final update as Vice President of User Services. It has been both an honor and privilege to serve you — our members and the entire AMSAT community — in this capacity. I am proud of what we have been able to accomplish, from implementing a cloud-based member management system to acquisition of the GridMaster awards program, and everything in between. I have had a great team of volunteers to work with, and I thank them for their hard work and dedication.

AMSAT's Member Portal is not only up and running, but it is off to a great start. It had long been a dream to transition from a PC-locked, dBase IV membership database to an online member management system. On May 1, 2020, this dream became a reality. AMSAT's Member Portal is a powerful tool that allows members to edit and update their membership record, print their membership card or download it to their phone, renew their membership, and register for AMSAT events from anywhere in the world, using a computer, tablet, or smartphone. In addition, members now have access to The AMSAT Journal archive, the AMSAT Symposium Proceedings archive, and the current amateur satellite frequency guide.

AMSAT's membership levels are currently at 4,100 members, an increase of 15.7 percent, or 557 new or returning members in just six months. I am not sure if this is a result of the enhanced member benefits provided by the new Member Portal, increased confidence in AMSAT's leadership and direction, or a combination thereof. Either way, it is a strong endorsement that we are on the right track.

While my proudest accomplishment as VP User Services may be our Member Portal, the most rewarding was getting to work with such a professional and enthusiastic group of volunteers. The AMSAT Journal, AMSAT News Service, IT, Website, TLE Updates, Awards, Online Store, Member Portal, Mailing Lists, Upcoming Satellite Operations, Hamvention, Hamcation, and AMSAT Ambassadors — all happen because some great AMSAT members generously donate their time to help deliver the quality of service our AMSAT members and the greater amateur satellite community

deserve. It has been an honor and a pleasure to work with you.

I am proud of what we have been able to accomplish under my tenure, but there is always room for improvement. One area in much need of attention concerns the discourse that occurred on the AMSAT-BB over the summer. The AMSAT-BB Mailing List consists of over 2,500 subscribers who gather to advance amateur satellite service through technical discussions, inquiries, and the sharing of ideas; however, certain bad actors have sought to subvert the free flow of information by injecting political rhetoric and making known false statements to evoke a response and sow doubt.

We need to restore the AMSAT-BB to its intended purpose — advancing the art of amateur satellite service. While the conclusion of our election and removal of certain subscribers has returned civility to discussions, we must remain vigilant to ensure a safe and supportive environment. AMSAT is a great place to grow and share in this exciting aspect of our hobby, but it is the people you meet and work with that truly give you the greatest satisfaction. While I may no longer be directly involved with User Services, my heart with always be with our members, the AMSAT community, and the entire User Services team. ⊕

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eBay Sellers Donate to AMSAT

Are you an eBay seller? One item, ten items, or a full-time business you can donate a percentage of your winning bid to AMSAT.

To do so, do not list your item with the basic listing tool, select advanced tools. eBay will give you a warning message that it is for large volume sellers, however this is where the eBay for Charity tool is found.

You can "select another nonprofit you love" and search for either AMSAT or Radio Amateur Satellite Corporation. Choose the percentage amount of the sale you would like to donate to AMSAT, and boom!.

When your item sells and the winning bidder pays, eBay will deduct the percentage from your take and forward it to AMSAT.

Sometimes we are getting rid of our old equipment, sometimes selling something new. In any case, please consider giving a piece of the pie to a new satellite and choose AMSAT for your eBay Charity.

For Beginners - Amateur Radio Satellite Primer (Part VII)

Keith Baker, KB1SF/VA3KSF
kb1sf@amsat.org

[Portions of this column previously appeared as "Spotlight on UOSAT-2 (UO-11)" in the May, 2012 edition of Monitoring Times Magazine *Thank you MT!]*

In this installment, I'll shine the spotlight on some amateur radio satellites our brethren in the United Kingdom have built, including one of AMSAT-UK's remaining satellites from their UOsat series (UO-11) that is both still in orbit and semi-operational. I'll also share some information on their (very popular) FunCube (AO-73) analog satellite.

By the way, if you are new to AMSAT membership and are just now reading your very first copies of *The AMSAT Journal* — or perhaps you are ready to (finally?) try your hand at satellite operation, this column is part of a continuing series of "getting started" primers in the *Journal* that I've written on how you, too, can get in on the fun of amateur radio satellite operation.

And now that most back issues of this magazine are online in AMSAT's Member Portal, you can start at the very beginning of this discussion. I suggest you start by downloading the September/October 2019 edition of the *Journal* that contains my first (updated) installment of these "getting started" columns. Hopefully, it (plus subsequent columns that have already been published in the Journal and those that will follow in the future) will help you to get up and running on the satellites —quickly!

UoSAT-2 (UO-11)

UO-11, also known as UoSAT-OSCAR 11, UoSat-2 or UoSat-B, was the second in a series of amateur satellites built at the University of Surrey in England. Its beacon remains active, although it is very unstable with irregular periods of transmission. Miraculously, the satellite has still been heard occasionally transmitting telemetry more than 36 years after launch! As I said, it transmits a beacon on 2 m, with inactive beacons on 70 cm and 2.4 GHz.

The satellite carried a so-called "Digitalker" (speech synthesizer), magnetometers, a CCD camera, a Geiger-Müller tube and
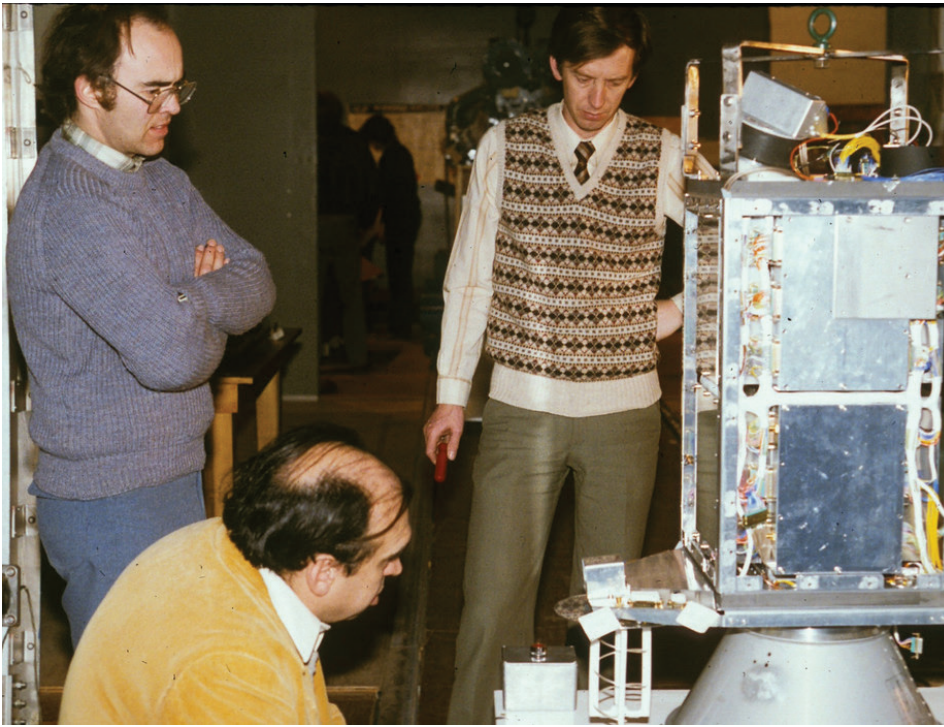
Figure 1 — Professor Sir Martin Sweeting, G3YJO, Director of the University of Surrey's Space Centre in England (left) oversees the final assembly of UoSAT-2 which later became UO-11 on orbit. (Courtesy: AMSAT-UK/SSTL).
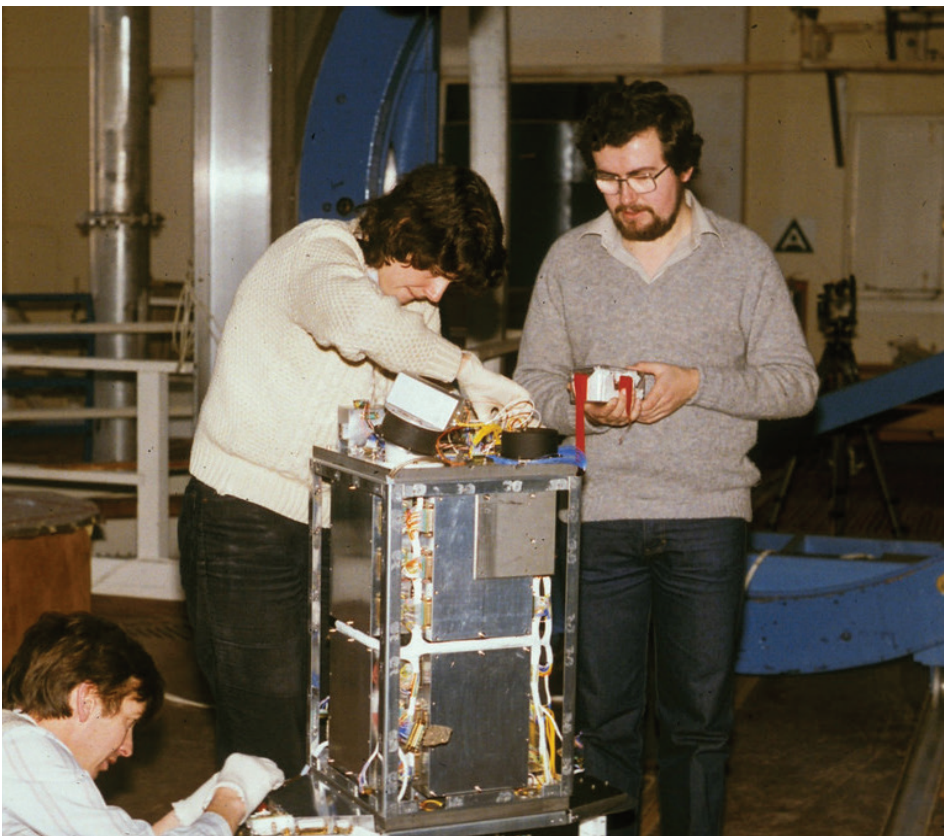

Figure 2 — Technicians put the final touches on UoSAT-2 (UO-11) just prior to environmental testing. Note the absence of the spacecraft's solar panels. (Courtesy: AMSAT-UK/SSTL).

a microphone to detect satellite vibrations caused by micrometeoroid impacts. Like its predecessor, UoSAT-2 transmits telemetry data on the VHF beacon at 1200 baud, using asynchronous AFSK, although all of its analog telemetry channels have long since failed.

A Brief History

UO-11 was launched on March 1, 1984 from Vandenberg AFB, California, with the aim of providing telemetry and other digital services for amateur radio and educational users. During its many years of operation, it has amazingly survived both long periods of eclipse and continuous full sunlight.

In 2002, its batteries began failing and, much like AO-7, it began operating principally with power generated from its solar panels — panels which were bought at a premium compared to those of UoSAT-1, the design having been space-tested by its predecessor. The satellite's so-called "watchdog timer" — a device to reset the satellite's main computer if all contact with the ground is lost — started suspending activity for up to three weeks at a time following numerous power anomalies.

Then, in 2005, all the satellite's analog telemetry channels failed. Long solar eclipses also caused UO-11's watchdog timer to completely reset the satellite from time to time, switching it off for approximately 15 days. In 2008, solar eclipses became a permanent feature of every orbit, sometimes causing the satellite to switch off after only one orbit. At that time, the satellite was not expected to be heard from again for any continuous period until 2019, when there would be some eclipse-free periods.

However, miraculously, the satellite started transmitting once again in November of 2008, followed by yet more long periods of silence. Then, after another long gap in observations, UO-11 resumed sending telemetry in December 2009, and has apparently continued its watchdog timer-controlled transmission regime ever since, although now on a very intermittent basis.

Sadly, the satellite's orbital condition has not otherwise improved apart from a small recovery of its battery power, allowing some broadcasts to continue into partial eclipse. As of late, the satellite has been heard from occasionally, sometimes with excellent signals reported from stations located around the world.
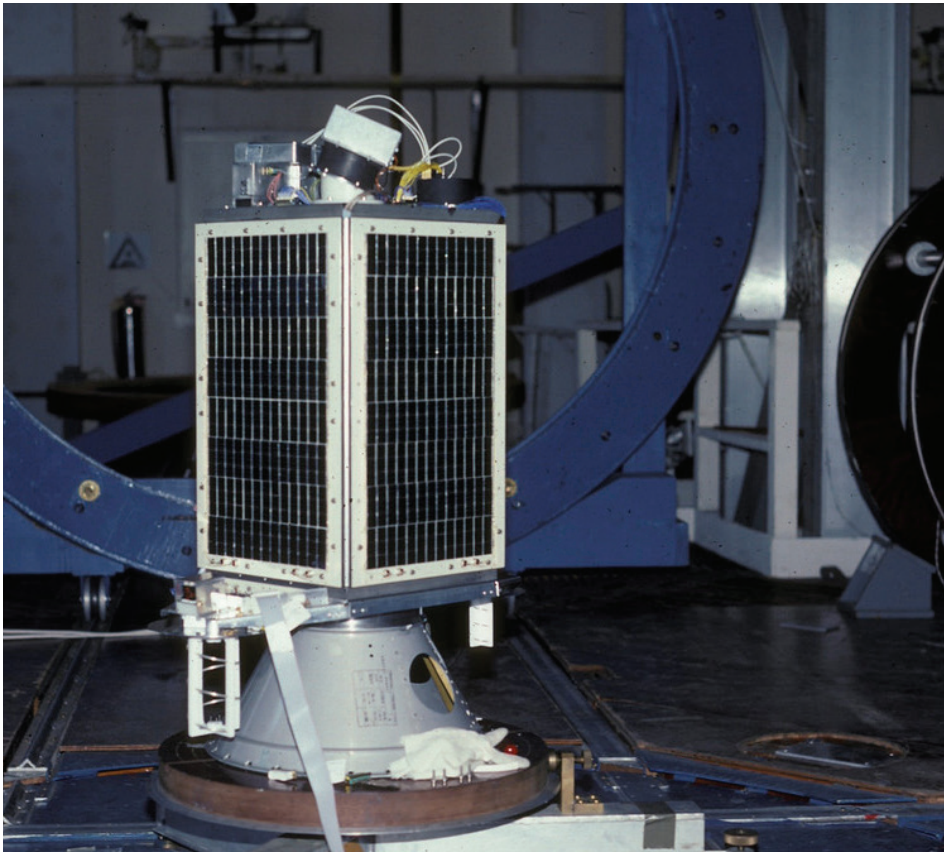
Figure 3 — UoSAT-2 (UO-11) is shown here mounted on its "shake table" with its solar panels attached. (Courtesy: AMSAT-UK/SSTL)

Solutions in Space BV.

The first FUNcube, built around a standard, 1-U CubeSat space frame, was conceived as an educational CubeSat with the goal of both interesting and then educating young people about radio, space, physics and electronics. It directly supports the United Kingdom's educational Science, Technology, Engineering and Math (STEM) initiatives as well as provides an additional resource for the GB4FUN Mobile Communications Center in England. The target audience for FUNcube consists of primary and secondary school pupils. To further this aim, FUNcube's 145 MHz telemetry beacon provides a strong signal for school pupils to receive using just simple antennas and ground station equipment.

A wide-band, relatively low-cost receiver board called a "FUNcube Dongle" has also been developed to aid in achieving FUNcube's educational goal. The dongle can be connected to the USB port of a laptop (along with a simple receiving antenna) so as to display telemetry and messages from the satellite in an interesting way. The satellite also contains a materials science experiment from which the school students can receive telemetry data that they can compare to the results they obtained from similar reference experiments in the classroom.

FUNcube-1 was successfully launched on November 21st 2013 on a Dnepr rocket from the Dombarovsky launch complex near Yasny in Russia and was placed in a 682 x 595 km orbit. FUNcube carries a 1200 bps BPSK telemetry beacon on 145.935 MHz, a linear transponder with a downlink pass band of 145.950-145.970 MHz for SSB/CW
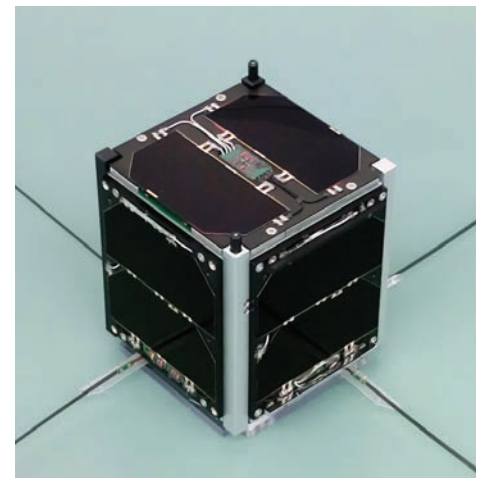

Figure 4 — UoSAT-2 (UO-11) was successfully launched aboard a NASA Delta II rocket from Vandenberg AFB, California on March 1, 1984. (Courtesy: AMSAT-NA)

When and Where to Listen

UO-11's VHF downlink frequency is on 145.826 MHz. There are no uplinks. OSCAR-11's VHF downlink has a unique sound, rather like a raspy slow Morse code signal. If you are receiving a very weak signal, I suggest you switch your receiver to CW or SSB. You should hear several sidebands around the carrier frequency, and you should be able to hear the characteristic Morse code-like sound on at least one sideband. You'll also need a clean (that is, " noise-free") signal to decode UO-11's downlink, and your receiver must be set to NBFM mode for such a decoder to work.

More information about UO-11 can be found on the AMSAT-UK website at amsat-uk.org/satellites/tlm/uosat-2-oscar-11/.

FUNcube-I (AO-73)

AMSAT-United Kingdom, in collaboration with AMSAT-New Zealand, has built and successfully launched a satellite they call "FUNcube" that features a 435 to 145 MHz linear transponder for SSB/CW operation. The project received major funding from the Radio Communications Foundation (RCF) in Great Britain and was developed in collaboration with ISIS-Innovative

Figure 5 — The flight model of FUNcube-1 (AO-73) is shown here with its VHF and UHF antennas deployed. (Courtesy: AMSAT-UK)

SELECTED FREQUENCY AND MODE DATA:

SATELLITE	Uplink (MHz)	Downlink (MHz)	Mode
UOSAT-2 (UO-11)		145.826	AFSK FM
UKube-1 (Transponder Not Yet Operational)	435.080 - 435.060	145.930 - 145.950 145.915, 145.840, & 437.475 2401.0	SSB/CW 1200 bps BPSK 1 Mbps QPSK
FUNcube-1 (AO-73)	435.150 - 435.130	145.950 - 145.970 145.935	SSB/CW 1200 bps BPSK

Figure 6 — Members of the UKube-1 team are all smiles as they pose with the fruits of their labor — the flight model Ukube-1. (Courtesy: Clyde Space)

Figure 7 —An artist's depiction of how the UKube-1 satellite might appear on orbit. (Courtesy: Clyde Space)

along with several onboard experiments, to carry a set of AMSAT-UK FUNcube circuit boards which provide a 1200 bps BPSK telemetry beacon on 145.915 MHz and (when it is finally activated) a linear transponder downlink on 145.930-145.950 MHz for SSB/CW communications with a linear transponder uplink on 435.080-435.060 MHz.

In addition, UKube-1 also carries a 1200 bps BPSK telemetry beacon on 145.840 MHz and a myPocketQub 442 on 437.425-437.525 MHz with 11 mW output using spread spectrum emission techniques along with a 1 W transmitter on 2401.0 MHz built by students and staff at the Cape Peninsula University of Technology (CPUT), Cape Town, South Africa. This transmitter downlinks high data rate mission data using up to one Mbps QPSK or OQPSK modulation.

At present, the other mission(s) of the satellite are continuing and there may be times when the 145.915 MHz FUNcube telemetry transmitter is activated. However, the amateur radio transponder is not expected to be available until later in the mission. Stay tuned to the AMSAT UK website (amsat-uk.org) for all the very latest information on this and future FUNcube projects.

Wrap Up

In future columns, I'll again be shining the spotlight on many other interesting past and future amateur radio satellite projects, as well as keeping you apprised of what AMSAT (and its world-wide sister organizations) are up to in space. See you then! 🌐

communications, with an uplink receiver that will tune from 435.150-435.130 MHz. More information about the FUNcube project is available at AMSAT-UK's website at amsat-uk.org/funcube/funcube-cubesat. There is also a website dedicated exclusively to the FUNcube at funcube.org.uk/. Information about the FUNcube Dongle is at amsat-uk.org/funcube/funcube-dongle-sdr. Indeed, for those not otherwise equipped to receive the "birds," obtaining a low-cost FUNcube Dongle may be just your ticket to getting in on some of the action.

Funcube-2 (UKube-1)

The UKube-1 satellite was successfully launched on Tuesday, July 8, 2014, at 1558 UT from Pad 31/6 at the Baikonur Cosmodrome in Kazakhstan and is Scotland's very first satellite. It was designed,

A 3D-Printed Parasitic Lindenblad for 70 cm — *Times Two!*

Curt Laumann, K7ZOO
Zachary Metzinger, N0ZGO

Editor's Note: To say that these are strange times would be a gross understatement. At The AMSAT Journal's "editorial offices," one of the strangest phenomena we have witnessed was the recent near-simultaneous appearance of two interesting and innovative articles by two first-time Journal writers on the exact same topic: using a 3D printer in the design and construction of the AA2TX parasitic Lindenblad antenna for 70 cm!

Initially, the editorial team reasonably believed that publishing two articles on the same topic in the same Journal issue might be redundant and not give readers the kind of value we strive to create. So, each editor separately reviewed both articles to determine which was "best." However, when we compared notes, no clear winner emerged.

Upon deeper review and reflection, we realized that having articles by two different DIY'ers who set out to tackle the same challenge would show how two innovators developed separate approaches to get there. That, we believe, goes to the heart of what inspires those drawn to amateur radio with a "maker mind," who almost always want to see what and how others designed and built something as they embark upon their own adventure to enhance their amateur radio experience while sharing their knowledge with others. — JK

Curt Laumann, K7ZOO

Introduction

At times, a project or endeavor is born out of frustration, knowing there just has to be a better, more modern approach. This is one of those stories. What follows is a description of not only the design, but also the design and manufacturing processes for a 70 cm Lindenblad I've been developing over the last couple of months. What a fun and rewarding project it's been!

While trying to combine my interest in portable operations and satellites, I ran across the Lindenblad antenna design, a near-perfect enabler of convenient portable satellite operations. About 15 years ago, Tony Monteiro (AA2TX) created and
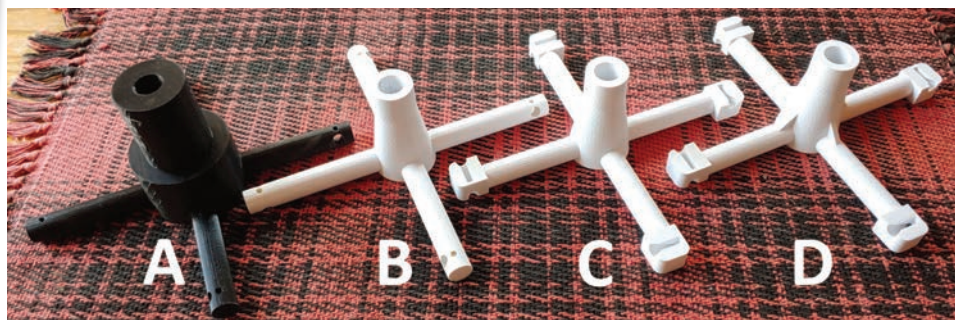

Figure 1.

published a very effective design, describing a novel 70 cm parasitic Lindenblad. The AA2TX design uses a centrally driven dipole surrounded by four tilted parasitic elements. One of the biggest challenges to construct a Lindenblad antenna is holding the parasitic elements in the crazy geometry defined by a Lindenblad configuration. The original article (2006) used irrigation parts, requiring careful alignment by hand and tedious bonding operations. Today — with the availability of 3D printing — it is possible to remove all of the critical alignments, designing these spacings and angles into a 3D printed part.

For those familiar with 3D printing, design and print files can be found in Thingiverse by searching for the call sign "K7ZOO."

Evolution of a Design: the Parasitic Element Support (PES)

When employing 3D printing it is relatively easy and quick to iterate a design with many prototypes. Rather than striving for an "almost complete" design before printing hardware, I chose instead to create a design at the 50% level and print it (Figure 1A). With that rather crude prototype in hand, the next design iteration became clear (Figure 1B), streamlining and lightening the overall form factor. This prototype was worthy of moving forward, and arrow shafts* were bonded onto the PES.

[*These arrow shafts were size "2219," with a diameter of 22/64 (0.344) inch, and the wall thickness is 19/1000 inch. The initial arrow shafts were used out of convenience, leftover from a previous project.]

With this prototype in hand, I clearly saw the arrow shafts were not sufficiently bonded in place; increasing the bond area was needed. Square volumes were added at the end of each arm, with a large bonding cavity to hold fiberglassing resin (Figure 1C). While probably not needed for structural purposes, small gussets were added (I thought they

looked cool!) with the final design form shown in Figure 1D. More than sufficient bonding area was now available, and the arrow shafts were very secure.

Along with changing the support structure, the diameter of the parasitic elements was changed from the original AA2TX design: arrow shafts (size 2219) were substituted in place of 1/8 inch aluminum rod. This was driven by a desire to make the antenna more mechanically robust. This minor change was not modeled in EZNEC and is not judged to significantly change the performance of the antenna. To further improve the manufacturability of the system, the final design was further refined to accommodate 0.375-inch diameter aluminum tubing.

3D Printing Notes

Most of the prototypes were printed using PLA material, as it has a wider tolerance to variations in printing (i.e., it's easy to print). PLA, however, does not survive ultraviolet exposure, and a much better choice for the final parts is PETG. When I switched from PLA to PETG with no changes in printing tactics, however, a small disaster occurred: the PETG contracted, and the end of the arms lifted off the printing surface. To rectify this problem a "skirt" of 20 print lines wide was added, substantially increasing adhesion to the printing bed. This tactic proved highly successful, and the PETG print remained firmly attached to the print bed. See bill of materials in Figure 2.

Assembly of the Alum Rods onto the PES

It was useful (and recommended) to create a heavy tool that supports and anchors the PES above the work surface. As an example, I cut a 6-inch length fencepost (4" x 4" redwood) and installed two screws on opposing sides (Figure 3). Using lightweight cord, I could tie the PES down to the top of the fencepost block. When installed on top of the fencepost block the parasitic elements should not touch the work surface.

This bill of material results in an assembly that holds the parasitic elements, and mounts that assembly to the driven dipole. Also incuded is a cylinder you can use to assembly both of the driven dipole elements "Dipole Joiner"		
Item	**Description**	**Qty**
Parasitic Element Support	PETG printed support structure for parasitic elements in AA2TX Lindenblad antenna.	1 ea
Parasitic Elements	Aluminum tubing, 0.375 in (diameter) x 11.75 inch (length). Wall thickness is not critical.	4 ea
Rubber End Caps	Round Caps, Vinyl Plastic, for 5/16" to 3/8" OD, 1/2" Inside Height, BlackMcMaster PN 9753K16	8 ea
Dipole Drilling Guide	PLA printed tool to accurately drill upper dipole element.	1 ea
Modeling Clay	Holds aluminum elements in place and seals against resin leaking during bonding operation.	25 g
Fiberglassing Resin	Used to bond the aluminum parasitic elements in place.	0.5 oz
Hardware, Mounting Parasitic Element Assembly	10-32: Nylon machine screw TBD inches long; SST nut / flat washer / lock washer	1 ea
Hardware, Driven Dipole Element	Machine screws: 6-32 x 0.5 inch (center conductor); 8-32 x 0.5 inch (shield)	1 ea

Figure 2.

Figure 3.

Figure 4.

The midpoint of the parasitic element was marked with a felt-tip pen and inserted into the PES. Fiberglassing resin will eventually be poured into the cavity at the end of each arm. Note or mark the area on the aluminum where the fiberglassing resin will bond to the aluminum. Remove the element and roughen the aluminum surface with 120-grit sandpaper. Re-insert the aluminum element, ensuring it is properly centered on the center of the support arm.

Roll about 5 grams of modeling clay into a cylinder, then wrap it around the lower point at which the aluminum element exits the PES (Figure 4). This clay will seal the gap, preventing any fiberglassing resin from leaking out during the bonding operation.

Mix 0.5 ounce of fiberglassing resin, adding enough activator for approximately 30 minutes of cure time. I was able to carefully pour the resin out of a 2 oz mixing cup into the bonding cavity. I used the shaft of a Q-Tip to drip the last amount of resin into the bonding cavity, achieving a nice fill amount (Figure 5).

When the resin is cured, install protective vinyl end caps onto the parasitic elements.

Installing the PES onto the Dipole

The vertical-driven dipole element is built per the AA2TX instructions. If you desire, you can substitute the dipole joiner (Figure 6) for the irrigation part that holds the two dipole elements. The diameter of the two through holes in the dipole joiner are designed for threads to be cut: 6-32 and 8-32.

With the aid of the drill guide (Figure 7) you can drill two mounting holes in the upper dipole. The following sequence is recommended:

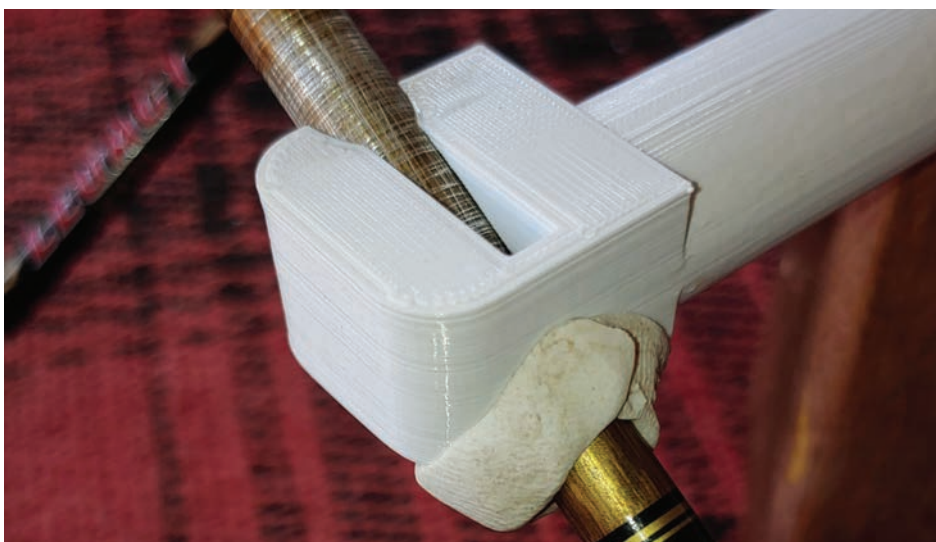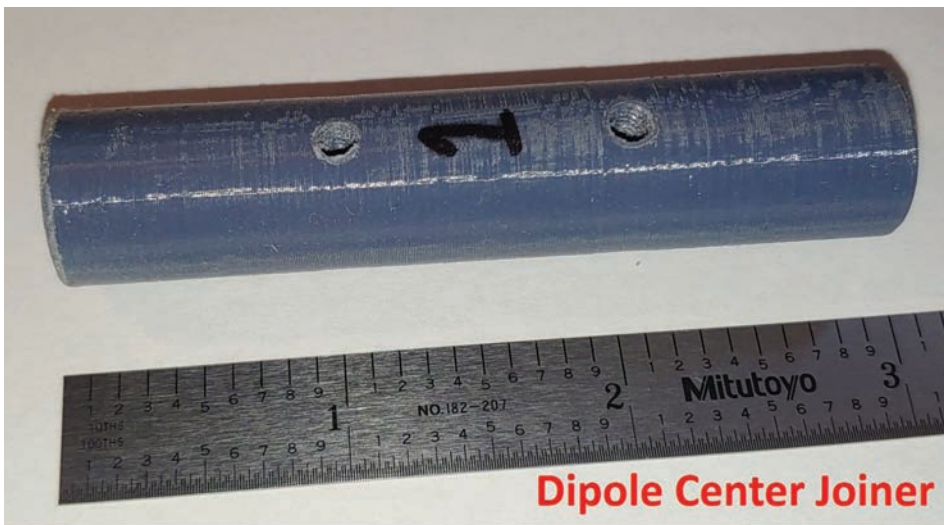(1) Mark the side of the upper dipole element 63.5 mm from the center of the dipole;

Figure 5.

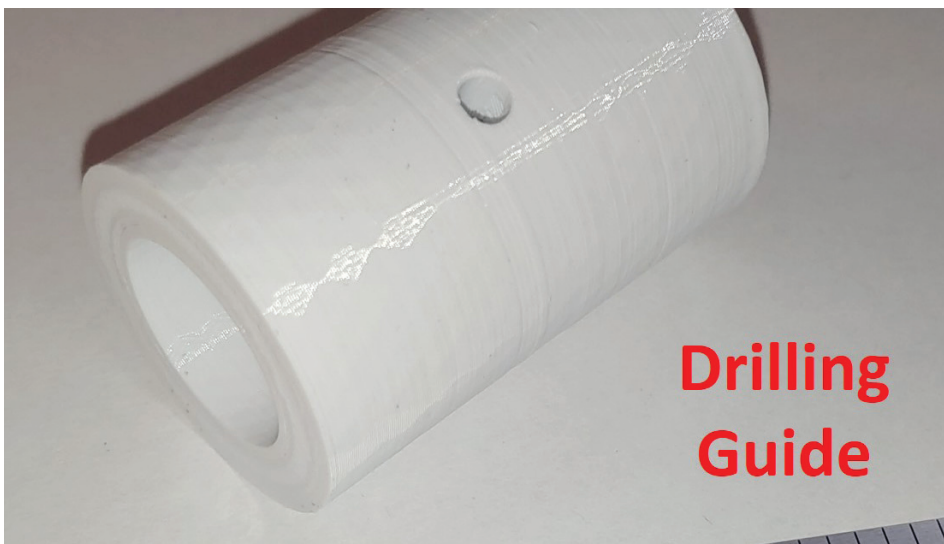

Dipole Center Joiner

Figure 6.

Drilling Guide

Figure 7.

(2) Drill only one wall of the vertical aluminum tube with a #16 (or 11/64 in) drill bit;

(3) Slide the drill guide over the upper dipole element; temporarily install a 0.5 in long #8 machine screw through the drill guide and the hole drilled in step #2;

(4) Put tape over the head of the screw to keep it in place; and

(5) Drill the second hole (#16 or 11/64 inch bit) using the drill guide as an alignment aid.

Install the PES assembly onto the dipole with a nylon 8-32 screw 1.5 inches long. Use a stainless steel nut and lockwasher.

On the Air Results

I can cite my own recent experience with it this past year. During Field Day 2020 in southern Arizona, I easily worked a station in Maine on CW, with the satellite at an elevation of about 4 degrees. Also, during Field Day, I made many SSB and CW contacts. My signal was easy to copy on the XW and CAS series on SSB. I sometimes turned the power down to 5 W to match the beacon strength on the CAS-4x satellites. At other times during a pass, I increased power to 75 W. I can copy my CW signal down to a degree above the horizon on many passes.

FM satellites are a different story, however. Without any significant gain, it is difficult to capture the satellite's FM receiver when competing with the >500 W EIRP of many home stations.

The measured SWR of my antenna is very good, <1.5:1 over almost the entire 70 cm band.

About the Author

Curt was first licensed in 1975 in Minnesota. He currently holds an Extra Class license and has explored many facets of the hobby. His current interests include: managing the University of Arizona K7UAZ station & mentoring students; Morse code; portable operations (SOTA, POTA, satellite grid roving, contesting); construction of various antennas and ham radio widgets; and 3D printing. Curt has worked as a physicist, design engineer, and process engineer (former certified Six Sigma Blackbelt). For a few decades Curt pursued flying: he is a licensed private pilot in airplanes, and a commercial pilot in gliders, and held a glider instructor certification. Over the last decade Curt returned to amateur radio as his primary focus.

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Zach Metzinger, N0ZGO

In an article published in the 2006 Symposium Proceedings, Tony Monteiro AA2TX (SK), presented an antenna derived from the classic Lindenblad design. AA2TX called his version a "Parasitic Lindenblad," and what made its construction unique was its design was considerably simpler than the original Lindenblad design. His design retained the omni-directional pattern in azimuth and optimized gain for lower-elevations, with a circular polarization pattern.

As this article will not cover the theory and development of AA2TX's design, the author highly encourages the interested amateur to read, "A Parasitic Lindenblad Antenna for 70 cm."

The parasitic Lindenblad design, as outlined in the original article by AA2TX, was built using mostly common hardware-store components such as CPVC (extra-chlorinated "gray" PVC) and rain gutter spacers. The dipole driven element used 3/4" O.D. aluminum tubing, and the polarizer elements were made from #8 AWG ground wire.

While this design was definitely simpler than the classic Lindenblad, the method of manufacture left some room for improvement. For instance, the aluminum driven element was only available from one supplier, and the construction of the antenna required relatively precise positioning of parasitic element assemblies and holes.

Fused Deposition Modeling

To simplify construction and leverage the most ubiquitous of today's hobbyist construction methods, a 3-D printed (FDM), the design was created to replace all of the PVC parts. Additionally, the driven dipole element was changed to use standard 1/2" copper water pipe (0.625" O.D.), and the polarizer elements are made from 3.2 mm brazing rod.

While bare copper does not hold up as well to the elements as aluminum, the author has had good experience with spray-painted copper tubing on a J-pole which was exposed to Texas weather for over 10 years.

The center hub design contains features to make assembly of the antenna quite simple. Looking down on the hub, you can see a bull's eye pattern, and this is mirrored on the underside of the hub. Into these circular recesses are pressed the driven element pipes, and they are retained by a friction fit
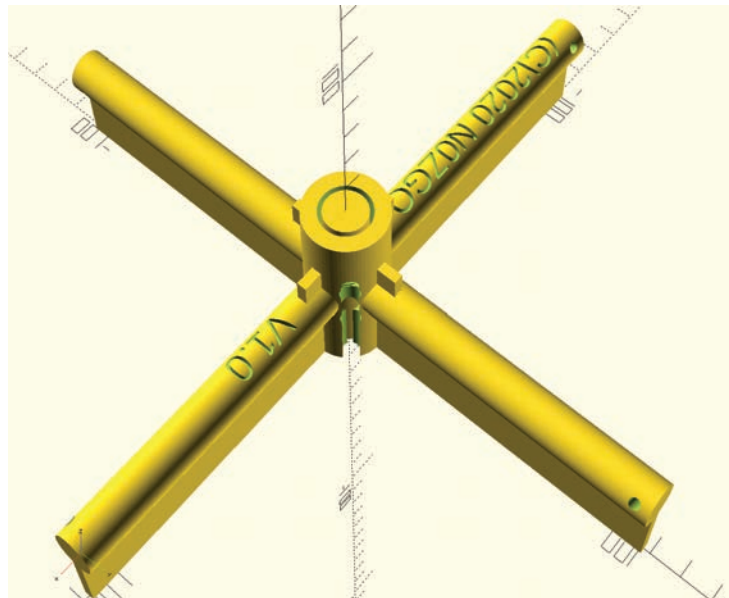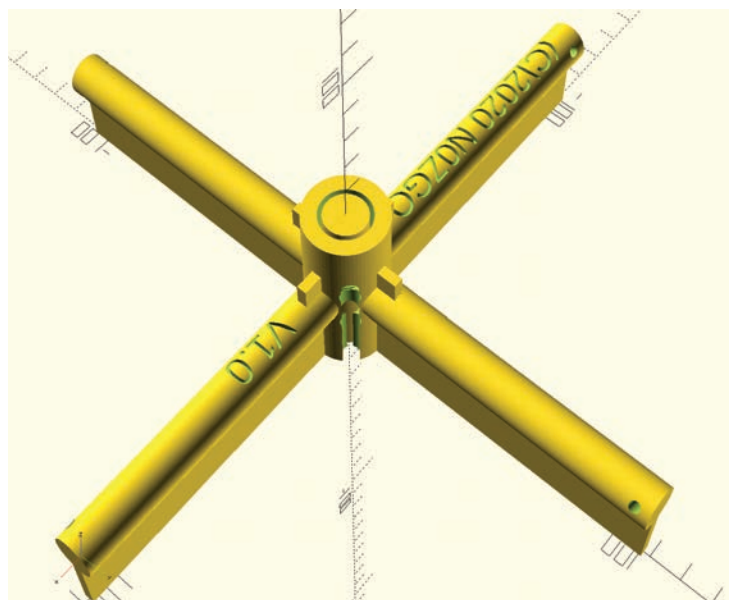

Figure 1.

Figure 2.

to the pipe.

Down one side of the hub's center cylinder, you can see a recessed groove which is designed to allow access to the ends of the driven elements and which will accept a coaxial cable with up to 0.240" O.D., such as RG-8, RG-8X, etc. See Figures 1 & 2.

On each arm extending from the hub, a hole has been designed to accept the polarizer element. These elements, made with brazing rod, are also a friction fit. The holes are printed into the design at the AA2TX-prescribed 30-degree angle off of horizontal An additional part was designed to adapt the lower element to a 1-1/2" PVC pipe for ease of mounting. The top side of this adapter has

the same bull's eye pattern into which the copper pipe end is inserted, and the bottom side has a slightly-tapered plug which is designed for a friction fit into the PVC pipe.

Printing

The entire design was printed on a Creality Ender 3 Pro printer, using PET-G filament. This type of filament is quickly becoming the author's go-to solution for all printing needs, as it produces minimal noxious fumes and has a plastic transition temperature (melts) nearly as high as ABS. It is also slightly less brittle and more elastic than ABS, which aids in assembling press-fit designs such as this one. The RF properties of PET-G have not been investigated, but are probably inconsequential at the design frequency. A
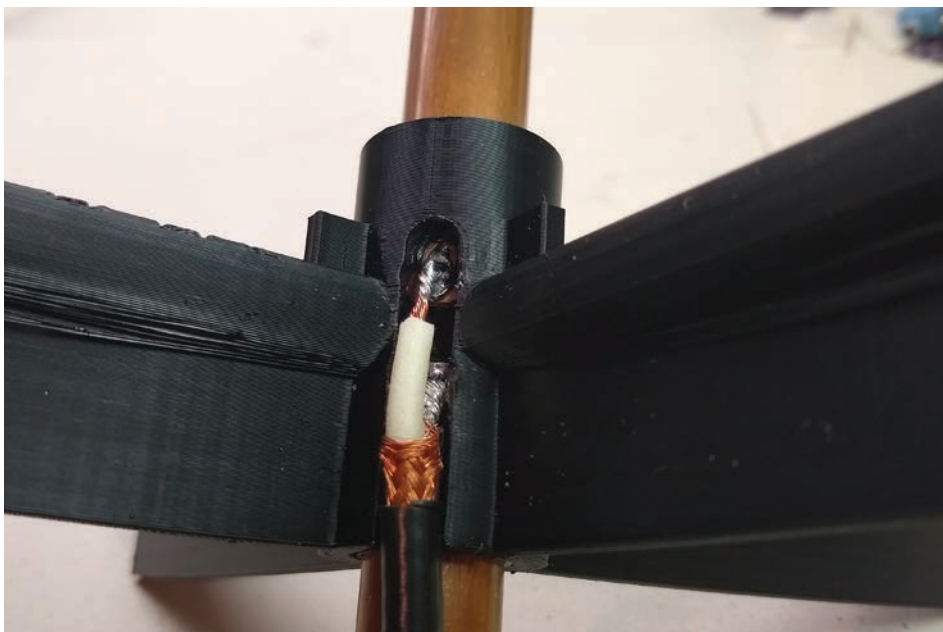
Figure 3.

Figure 4.

PET-G replacement turntable drive has survived in the author's microwave oven for many months, with no significant heating noted. See Figure 3.

The hub and adapter were printed with 20% infill, and a 2-layer raft was utilized on the hub print. This helped to avoid warping and pull-up of the polarizer arms.

Total print time with the Creality Ender3 Pro, using an extruder temperature of 210C and a bed temperature of 75C, 20% infill, and a two-layer raft was approximately 7 hours. Readers who do not have a 3-D printer may choose to have a third-party company, such as Shapeways or Craftcloud, print the design.

Assembly

Cut two 1/2" copper pipe driven elements to 6-1/16" (15.4 cm) and clean the copper

on one end of each element 1" with a gentle abrasive or sandpaper. The coax will be soldered to these cleaned surfaces.

Cut four polarizer elements from 3.2mm brazing rods into 11-3/4" (29.8 cm) lengths.

Remember that the ferrite sleeves must go on the coax before both the antenna and connectors are soldered. Now would be a good time to check if this is an appropriate moment to do so.

Strip the coax cable insulation back approximately 1" and un-weave the shield braid. Then, move all of the shield wires to one side of the coax and twist into a wire-like shape. This will be soldered to the lower copper pipe element, on the end just cleaned. Before doing this step, refer to the picture and note that the shield has been soldered to the pipe about 1/2" from the end of the element. See Figure 4.

Next, remove the insulation around the center conductor, leaving approximately 1/8" (3 mm) of insulation to guard against shorting the shield to the center conductor. Lightly tin the center conductor, taking care not to melt the insulation.

Insert the lower copper pipe element into the underside of the hub, making sure that the soldered shield connection rides up through the groove. If RG-8X is used, guide the coax into the round hole lateral to the groove, and it will be retained neatly in the hub.

Place the end of the copper pipe on a block of wood and lightly tap the top of the hub with a rubber mallet or block of wood. Ensuring that the copper pipe is bottomed-out in the hub will guarantee the proper element-to-element spacing. Insert the top copper pipe, cleaned side into the hub, and repeat the gentle seating procedure with the mallet.

The next step is to solder the coax center conductor to the top element. This looks harder than it really is, and can be made easier if liquid flux is used on the copper pipe surface before soldering. Through the groove in the hub, first apply flux and then tin the surface of the pipe. The PET-G may melt a small amount around the access hole, but the structural integrity of the design will not suffer.

Once the pipe is tinned, cut the center conductor to length, which can easily reach the tinned area on the top element, and then solder the two together. The result does not have to be particularly pretty, but a cold

Figure 5.

solder joint should be avoided.

The polarizer elements are now inserted, one into each arm of the hub, with equal lengths protruding from the arm. It may help to use a small drill bit or reamer to clean up the hole. Caution is advised, as being too aggressive in cleaning out the holes may cause the printed layers to split or crack. If the elements seem loose, epoxy or cyanoacrylate can be applied to fix the element in place.

If the antenna is to be mounted with a PVC mast, insert the lower element into the adapter bull's eye and tap lightly on the top of the antenna to seat it.

For outdoor use, which the author has not yet attempted, a 1/2" pipe cap should be added to the top driven element and the coax/access groove should be sealed with an RTV compound. Additionally, the hub could be masked off and the copper pipe painted with any common outdoor spray paint. The bronze polarizer elements will not significantly corrode in weather but could be painted for uniformity.

Performance

The test antenna is currently located inside the attic of the author's home (Figure 5). A homebrew low-noise amplifier is attached to the antenna via a short run of coax, and powered by a DC bias tee in the shack.

In the author's experience, the parasitic Lindenblad performs well enough to hear AO-27 and RS-44 loudly, and somewhat less well to receive SO-50.

This antenna will likely remain in service for telemetry collection when the GOLF series of satellites are launched in the coming years, as they transmit on 70 cm.

Future Work

The OpenSCAD design files for this antenna are available from www.n0zgo.net/3d-lindenblad/ and have a BSD-like license for other amateurs to use or improve on.

Of particular interest, for the enterprising experimenter, are antenna-range tests to validate that the reduced diameter of the center element does not adversely affect the antenna's pattern.

The author wishes to thank Terry Osborne (ZL2BAC) for re-modeling the antenna in EZNEC to determine the impact of reducing the driven element diameter. ⊕

In Search of the Ultimate DX

Scott Tilley, VE7TIL

On October 6, 2020, Mars shone brightly in the night sky as it reached opposition with the Earth coming as close as it does to us for the next 26 months[1]. The close approach allowed observers the world over to take detailed images of the planet through even small telescopes. It also allowed for an interesting DX opportunity using a small Deep Space Network (DSN) antenna quickly erected in my backyard, see Figure 1. The Mars Reconnaissance Orbiter (MRO) as it spun around Mars on its mission of relaying communications and generating stunning views of its surface was heard audibly in this modest antenna. Cruising in deep space to join MRO[2] is an intentional fleet of three spacecraft from China, United Arab Emirates and the U.S.A. All launched in the summer of 2020 to continue our scientific study of the red planet as our low energy launch opportunities to get to Mars are also spaced approximately 26 months apart. So there are a few interesting objects to study within reach of the amateur DSN observer to hear the ultimate DX and do some amateur radio astronomy.

Mars' orbit is not circular like the Earth's largely is and, as a result, the distance between Mars and the Earth varies during each 26-month close approach from 55.7 to 101.4 million km[3]. In radio speak, that's a difference of 5.2 dB in the free space path loss. We had a particularly good opposition this year with the closest approach being a mere 62.7 million km which only diminished the best case signal by 0.9 dB, see Figure 2 to get a sense of the vast path losses involved. Therefore, it was a good time to try to hear Martian signals with a small aperture antenna as you could use something with about half the aperture to obtain the same result as a distant opposition.

The Deep Space Network (DSN) uses the X-band range of frequencies from 8400-8450 MHz for communication with objects beyond the Earth-Moon system. X-band is used for a number of reasons for deep space communications. The two primary reasons are the antenna gains for their size are higher than lower frequencies and X-band is just below the frequencies that are affected by rain fading found on higher bands thus providing a very reliable link for deep-space vehicles. This is the reason that

Figure 1 – A view of the 66cm Deep Space Network (DSN) antenna located in VE7TIL's backyard. (All images are credit Scott Tilley VE7TIL unless otherwise noted.)
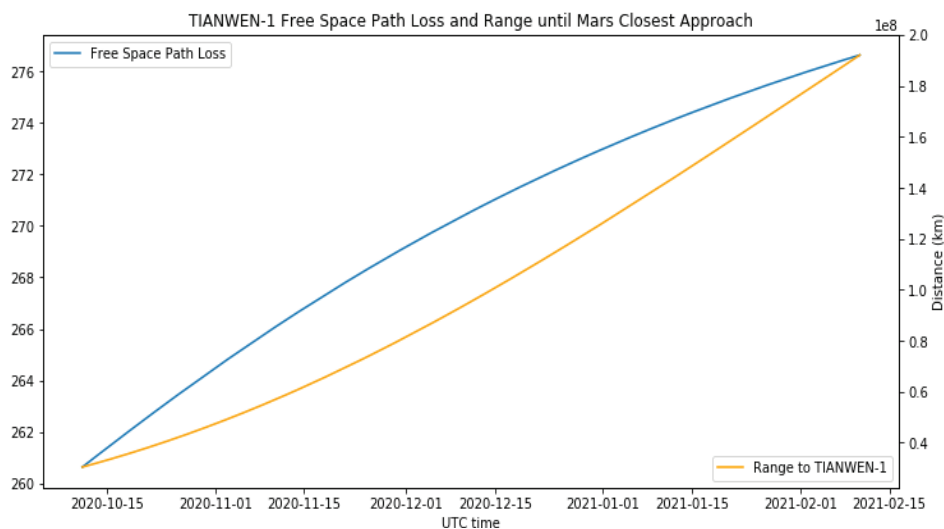

Figure 2 – TAINWEN-1 distance and free space path loss to Mars. Using this plot and the signal level observed from TIAWEN-1 it is estimated that the spacecraft's signal will exceed a signal-to-noise ratio of 10dB upon arrival at Mars making it audible even then.

governments have a large Space to Earth spectrum allocation from 7200-7750 MHz and Earth observation spacecraft have the band to send high-resolution data from Earth orbit between 7750-8400 MHz. Figure 3 provides a stunning example of what amateurs are receiving on the X-band Earth observation band. As it turns out these government and Earth observation missions provide great test signals to use as you build an amateur DSN station. Lunar and near-Earth exploration missions can be found

on the 8450-8500 MHz band which will become heavily used after next year's SLS 1 launch of a large number of small satellites into lunar and near-Earth space.

On the night of October 4, 2020, I aimed my small 0.6m dish at Mars and was able to hear in the speaker MRO's quickly drifting carrier[4]. The rapid drift I heard was caused by the relative motion of both the spacecraft and us here on Earth and this is known as the Doppler effect. Understanding that the

change in frequency is related to the relative velocity of the observed and the observer, I patiently tracked Mars and recorded the signal over the course of a couple of hours. It traced out a sinusoidal shape with a peak and a valley. Measuring the time between these maxima and minima allowed for the determination of the orbital period of MRO at 112 minutes, see Figure 4. Using Kepler's Third Law of Planetary Motion, I calculated the nominal altitude of MRO at about 274 km[5]. With further observation, one could begin to determine other orbital elements as well. All this from an unmodulated carrier 62 million km away, an old 0.6 m dish antenna and the wonders of software-defined radios (SDRs).

Building a suitable receiver for DSN work is a challenging project but with recent advances in SDRs and a wide array of surplus and new components available it is within the range of an amateur builder with modest skills and time. The primary things one needs are a dish antenna, a feed for that antenna and a down converter to a suitable intermediate frequency (IF). The down converter also needs a very stable local oscillator reference (LO) as any error in it will have a very deleterious effect on the performance of the down converter and make it unusable for scientific study of the signals being detected or worse those signals won't be found. See Figure 5 for a block diagram of the VE7TIL X-band down converter design.

The local oscillator I choose to use was made by Dieter Leupold, DF9NP[6]. I was attracted to his design as it allowed for a choice of LO frequency and could be readily locked to a GPS disciplined oscillator (GPSDO) of 10 MHz. To allow for monitoring of the entire X-band space communications band from 7100 – 8500 MHz I choose an LO frequency of 6800 MHz which required some assistance from Dieter to push his design a bit to allow this to happen. This placed the IF range from 300-1700 MHz which is ideally placed for use with most common SDRs. I choose to use an ETTUS B200 for the IF receiver as it too could also be locked to a 10 MHz GPSDO. Speaking of the GPSDO, Leo Bodnar Electronics manufactures a "mini precision GPS reference clock" that allows one to choose any frequency from 400 Hz to 810 MHz. I used one and set it up as a 10 MHz GPSDO for the entire station. After ensuring it has the latest firmware and control parameters installed it provides excellent performance as the station's frequency reference.

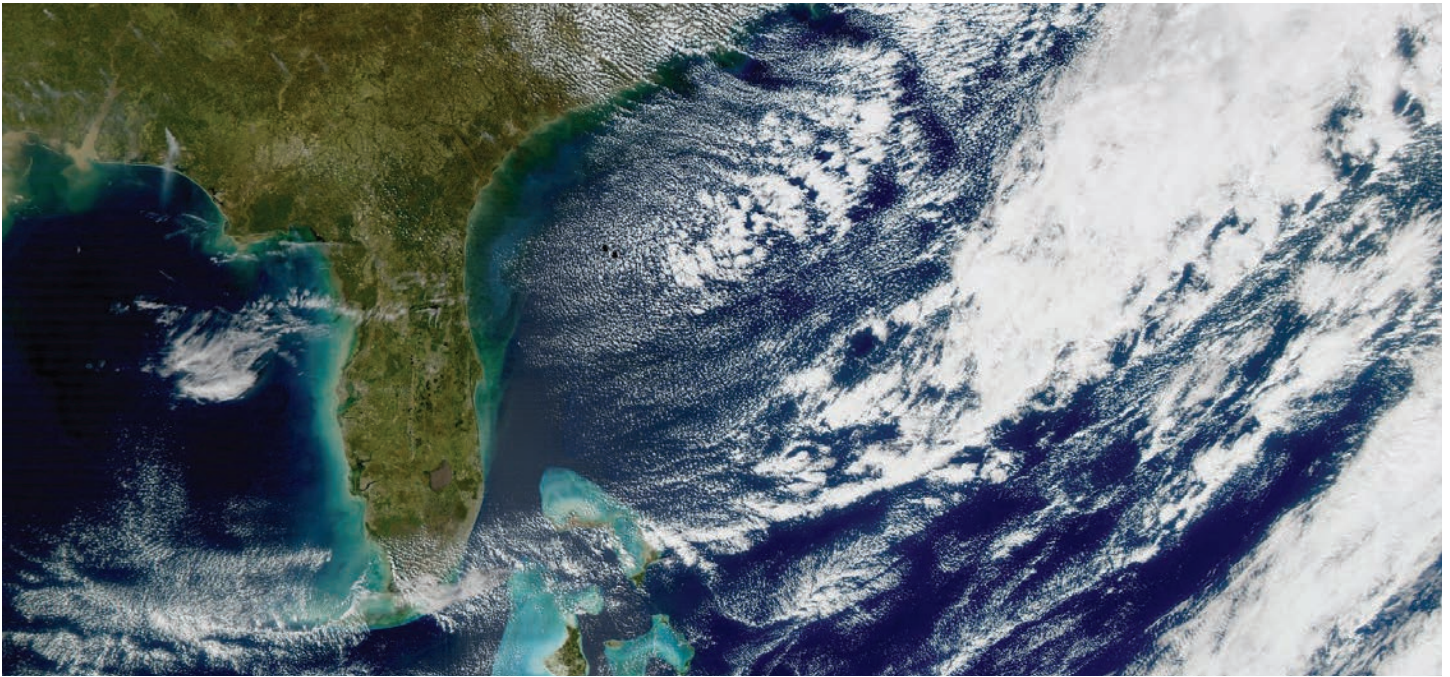Paul Marsh, M0EYT, is a well-respected

Figure 3 – Using homebrew software and hand tracking a 3m dish, Jean-Luc Milette of Quebec decodes and posts incredible images from various missions in Earth orbit sending their high bandwidth data back to Earth on X-band. This is NASA's AQUA looking back at Cape Canaveral. (Image Credit: Jean-Luc Milette.)
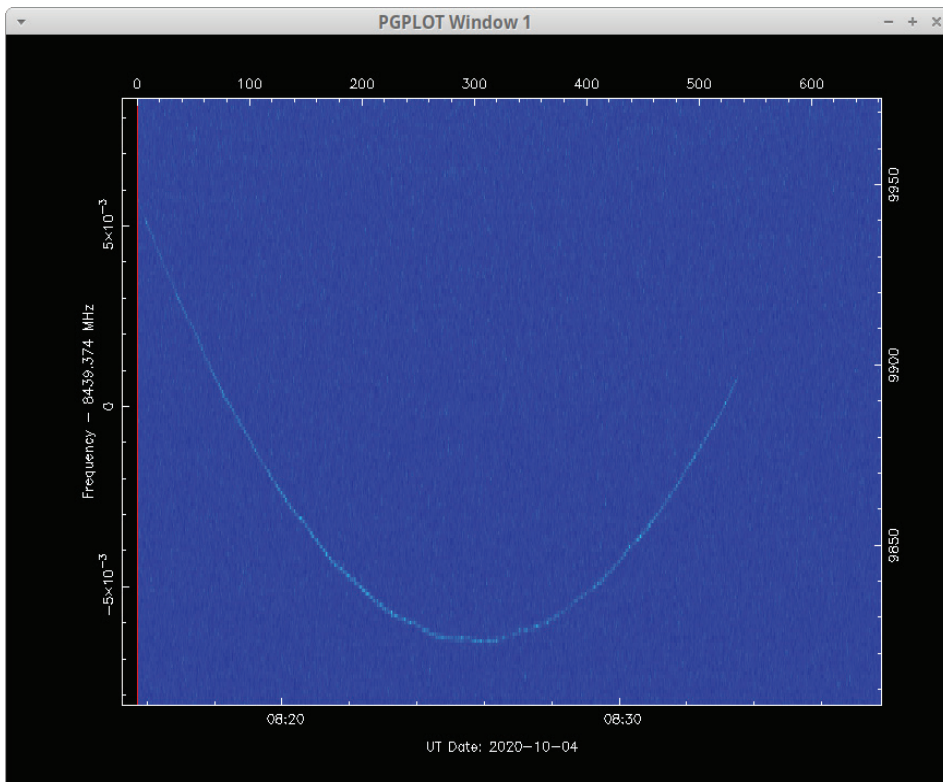

Figure 4 – You can learn a lot about a spacecraft from nothing more than its carrier signal. The signal is affected by the Doppler effect revealing the relative velocity of the space vehicle and even around Mars reveals the secrets of MRO's orbit with a period of 112 minutes and a nominal altitude of 274 km above the Martian surface.

amateur DSN observer and maintains the popular satellite radio observing website uhf-satcom.com. Over the years, he has come up with a marvelous DSN dish feed arrangement that he provides parts for[7]. Cleverly designed using copper plumbing bits and a dash of machining, he made the obtaining of a suitable dish feed easy. I chose to attach the detector to my depolarizer using a pipe coupler and a hose clamp allowing for on the fly changes from LHCP to RHCP.

In order to make the system perform as well as it possibly could, it needed a low noise amplifier (LNA) at the feed to ensure the lowest possible noise figure to hear the faint emissions from deep space. I initially chose the commercially available Lotus Communications Systems LNA2G18G with a specified noise figure (NF) of 1.4 dB. While the amplifier worked well, I found that Y-factor tests revealed it did not seem to be performing as well as I'd hoped. But it did allow me to hear MRO on that night at opposition! I then upgraded to the KU LNA 8000 B WG, Super Low Noise Amplifier with a 0.8 dB NF. Y-factor testing after installation revealed expected performance and the amplifier is now a permanent part of my DSN station. After the LNA, I have added a bandpass filter. Depending on the area of X-band of interest, I remove and install one of the filters I have found surplus over the years, see Figure 5. Finally, the all-important mixer used is a MACOM M14A from a surplus Precipitation Occurrence
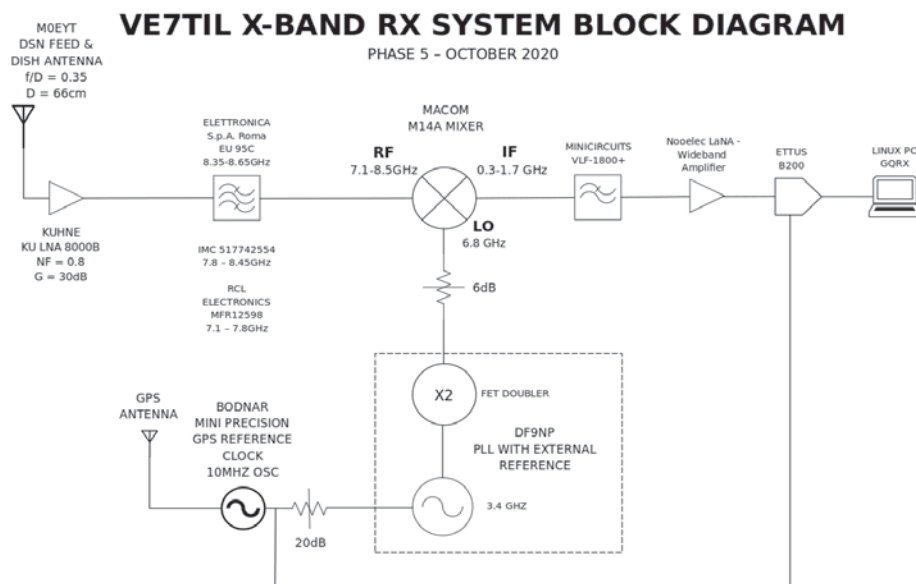
VE7TIL X-BAND RX SYSTEM BLOCK DIAGRAM
PHASE 5 – OCTOBER 2020

Figure 5 – A block diagram of the VE7TIL X-band down-converter. The system is set up to allow for monitoring from 7100-8500 MHz a range of frequencies used by government Space to Earth traffic, Earth Observations, Deep Space Communication and Science mission around the Moon and Earth.
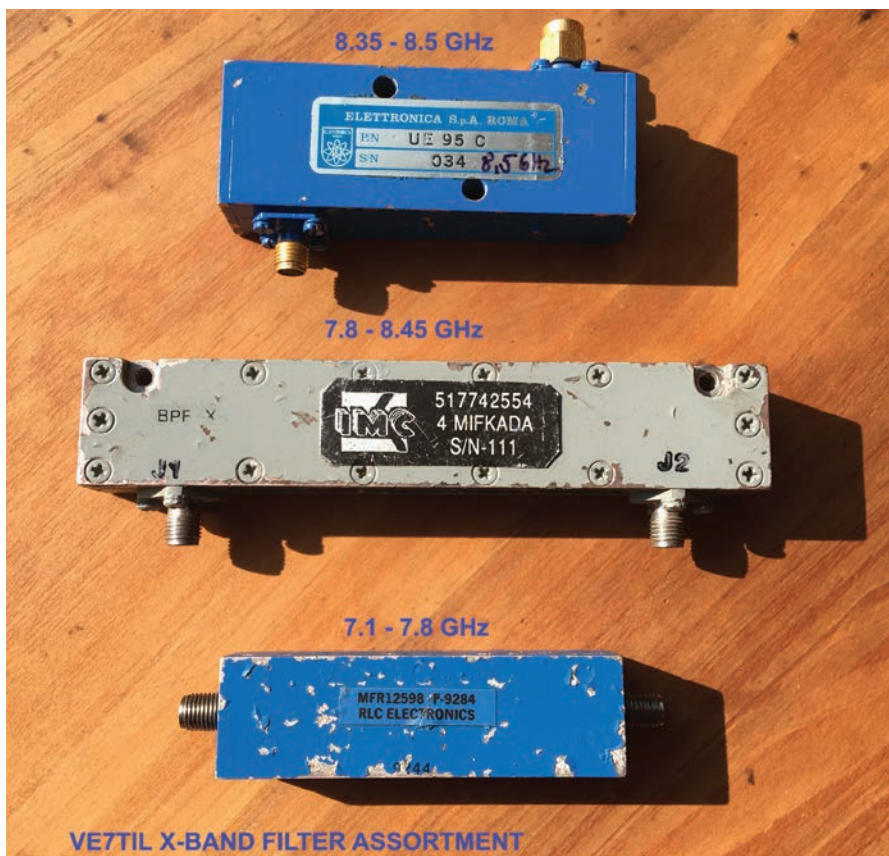

Figure 6 – Surplus bandpass filters can be easily found for X-band segments of interest. Here's the assortment accumulated in VE7TIL's junk box.

Sensor System (POSS). Using a smattering of attenuators, filters and an IF amplifier to ensure everything in the system was fed properly, I assembled the converter and mounted it at the feed of the dish to minimize losses.

The software I use is LINUX based. Data is collected using Cees Bassa's Sat Tools Radio Frequency (STRF)[8]. This tool allows for the quantitative collection of frequency and signal power data for analysis. With it, one can perform science and make accurate measurements and observe otherwise invisible events in deep space. I used the same software to assist in the recovery of NASA's IMAGE spacecraft in 2018.

The final element of my mini DSN station was to set up a suitable tracking mount that could keep my small dish aimed at an object in deep space and maintain its narrow beam on spacecraft distant from Earth. One of my design goals was to keep the station simple so I turned to a Celestron SLT telescope mount that I have used for years to optically track satellites with. The mount is conservatively rated for a maximum load of about 9 lbs. So, I went to work and balanced out the cantilevered dish mass with a movable custom cast weight on an arm extending from the back of the dish antenna. Using the Sun as an alignment tool, I was able to accurately calibrate the mount and track Mars and the various missions heading there for well over a month now. I use the sidereal tracking rate after aiming the dish each session at the desired target. The small non-sidereal motion of the spacecraft in a few hours of observing is not a concern with the fairly wide beamwidth of my 0.6 m dish.

The first signal I found in deep space was not MRO, rather TIANWEN-1 (TW-1) launched in July 2020 by China on an ambitious exploration mission of Mars. TW-1 has a huge signal for a spacecraft in deep space approaching 30 dB over the noise when Mars was in opposition. Interestingly, a small group of amateurs was able to find the spacecraft's signal shortly after launch (no publicly available position information was provided by China) decode it, and calculate its trajectory from the telemetry data[9]. Now a decoder is running each day at AMSAT-DL's Bochum ground station to collect the spacecraft's telemetry with a 20 m antenna. Since my station became active, I have been obtaining high-resolution nightly observations of the signal's frequency and intensity and have been able to take note of maneuvers made by the mission as it tweaks its trajectory. Using this data I have been able to correlate the accuracy of the state vectors
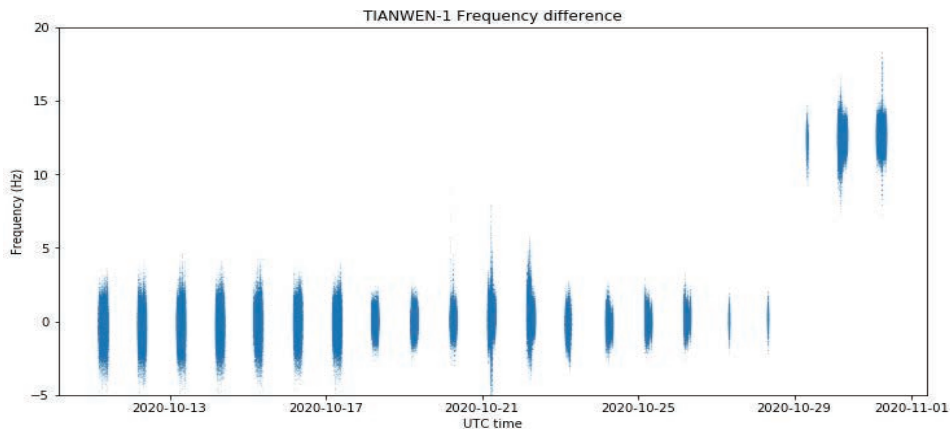
Figure 7 – Rather than just tick off each spacecraft I hear in deep space I like to perform some science with the data collected. Therefore, having an accurate and stable frequency reference is a must. Here TIANWEN-1 reveals it performed a trajectory correction maneuver (TCM-3). Evidenced by the ~12.5 Hz increase in frequency shown in the plot. This relates to a ~0.44 m/s change in line of sight velocity between TW-1 and us here on Earth caused by it firing its thrusters to dial in its arrival window at Mars.

decoded by the amateurs at Bochum ground station in Germany. My measurement of the effect of trajectory correction maneuver 3 (TCM-3) is shown in Figure 7.

Later in October, I was rewarded with signals from the Emirates Mars Mission – Hope (EMM)[10]. The signals, while not as strong as those from TW-1, were still audible at over 60 million km. To date, I have not heard from the Mars 2020 mission carrying the rover Perseverance as I understand it is using a low gain antenna with signal levels at Earth approximately 20dB lower than EMM. Finding deep space signals does require some calculation to determine the Doppler adjusted frequency. Using JPL Horizons[11], one can calculate this Doppler offset[12] using the range rate of the particular mission and know where to listen for the signal as well as provide you with aiming information for spacecraft in deep space.

As you can see, there is a lot of interesting and fairly loud signals to be monitored in deep space by modest amateur setups. If you take a bit of care you can turn your hunt for the ultimate DX into a fun and educational amateur astronomy project and study the trajectories and orbits of objects millions of km from home and take a front-row seat in observing and even participating in humanity's space exploration efforts.

This article is dedicated to Nicholas "Rusty" Rushton, VA7BY (SK), who inspired and supported my work.

Footnotes:

[1] skyandtelescope.org/astronomy-news/see-mars-best-view-until-2035/.

[2] mars.nasa.gov/mro/.

[3] www.universetoday.com/tag/mars-opposition/.

[4] "RADIO SIGNALS FROM MARS", spaceweather.com/archive.php?view=1&day=06&month=10&year=2020.

[5] See page 207, descanso.jpl.nasa.gov/monograph/series13/DeepCommo_Chapter6--141029.pdf.

[6] Local Oscillator, www.df9np.de/Contents/PLL_6GHz.pdf.

[7] DSN feeds, uhf-satcom.com/forsale.

[8] Sat Tools RF, github.com/cbassa/strf. Other software includes GQRX by Alexandru OZ9AEC and various GMAT and Jupyter-Notebook Scripts written by Danial EA4GPZ and myself. github.com/ScottTilley/tianwen1.

[9] Achim DH2VA, Mario DL5MLO and James G3RUH), Paul M0EYT, http://r00t.cz, Daniel EA4GPZ. amsat-dl.org/en/chinese-mars-probe-tianwen-1-successfully-received-by-amsat-dl/.
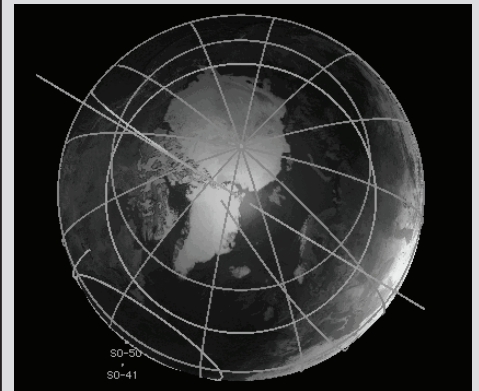
[10] Emirates Mars Mission, www.emiratesmarsmission.ae/.

[11] JPL Horizons, ssd.jpl.nasa.gov/horizons.cgi.

[12] M0EYT Amateur DSN Worksheet, https://pjmarsh.co.uk/DSN.xls.

Support AMSAT

AMSAT is the North American distributor of SatPC32, a tracking program for ham satellite applications. Version 12.8d features enhanced support for tuning multiple radios. Features include:

1. The CAT commands of the IC-9100 have been extended again. The program now also controls the DV mode (DV for 'Digital Voice') of the radio. With the FT-817 the program now additionally supports the CWR mode.

2. All SatPC32 programs now process significantly larger Keplerian element source files. Especially because of the numerous new Cubesats, the number of data sets contained in the source files has increased significantly. For example the file Cubesat.txt currently contains data for nearly 400 satellites.

3. In all programs (SatPC32, SatPC32ISS, Wisat32, WinAOS and WinListen), the list of satellites contained in the source file ('Available' list in menu Satellites) is now displayed in alphabetical order to facilitate locating individual satellites.

4. The program SatPC32ISS now also allows the creation of up to 12 satellite groups. The new Cubesats have also increased the number of 'in-band' satellites. Originally, in-band operation in amateur radio was only available at the ISS.

5. In order to accelerate a change between the individual satellite groups, the 'Groups' window can now be called up by clicking on vacant areas of the main window, except in the Satellite menu. Such free positions are located on the right and left of the frequency window.

6. In the Satellites menu the data sets of the satellites contained in the active source file can now be displayed. When called, the data set of the currently selected satellite is displayed. The feature helps you to immediately know the identifier of the satellite.

7. The program has improved control of the sub-audible tone required by some satellites. The program can now automatically switch the sub tone on/off when switching between PL tone satellites and others, changing between u/v and v/u satellites, changing the group, closing the program, etc.

A registration password for the demo version may be obtained for a minimum donation of $40 for members and $45 for non-members. Order by calling 1-888-322-6728. The author DK1TB donated SatPC32 to AMSAT. All proceeds support AMSAT.

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